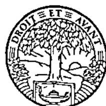
Clinical Orthopaedics

ANTHONY F. DePALMA
Editor-in-Chief

With the Assistance of the
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Number Sixteen



J. B. LIPPINCOTT COMPANY
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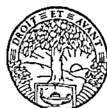
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Soft-Tissue Tumors, 1961
Disorders of the Shoulder Joint, 1961
Back Disorders in Children, 1961
Diseases of the Hip in Children, 1961
Disorders of the Cervical Spine, 1962
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Original typed copy of the manuscript, together with 2 carbon copies, a short synopsis of approximately 200 to 250 words for translation into Interlingua, and illustrations, should be submitted by February 1 of each year to Dr. William Minor Deyerle, Secretary, Association of Bone and Joint Surgeons, 2222 Monument Avenue, Richmond 20, Va.

All articles submitted must be in English.

Manuscripts should be typed double spaced on one side of standard typewriter paper, leaving wide margins. While every effort will be made to guard against loss, entrants are advised to retain copies of manuscripts submitted. All pages should be numbered. Dorland's *American Illustrated Medical Dictionary* (Edition 22) and Webster's *New International Dictionary* (Edition 2) should be used as standard references. Scientific names for drugs should be used when possible. Copyright or trade names of drugs should be capitalized. Units of measurement—e.g., dosage—should be expressed in the metric system. Temperature should be expressed in the degree centigrade.

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Bunnell, Sterling: Surgery of the Hand, ed. 3, pp. 176-187, Philadelphia, Lippincott 1956.

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Jones, J. B., Driscoll, A. J., Jr., and Hallock, H.: Ischiofemoral arthrodesis of hip, J. Bone & Joint Surg. 38-A:1117-1125, 1956.

NICHOLAS ANDRY AWARD COMMITTEE
Association of Bone & Joint Surgeons
Wm. Minor Deyerle, *Secretary*

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GENERAL ORTHOPAEDICS

Section III

ITEMS

1

Royal Whitman (1857-1946)

SAMUEL KLEINBERG, M.D.

At my request, the following biography of Royal Whitman was written by his long-time associate, Samuel Kleinberg. It was completed 6 weeks before his death in 1957; therefore, it is Samuel Kleinberg's last contribution to the literature of orthopaedic surgery. This biography has been held for a suitable number of *Clinical Orthopaedics*. It is not often recalled that besides his well-known work on the hip joint, Whitman was an ardent pioneer in the study of foot deformities.

EDGAR M. BICK

Dr. Royal Whitman was born in Maine in 1857. He was graduated from Harvard Medical School in 1882 and for a number of years practiced in Boston. However, the atmosphere of his hospital affiliation apparently was not congenial, and in 1889 he moved to New York and began his orthopaedic work at the Hospital for Ruptured and Crippled under the leadership of Dr. Virgil P. Gibney, a pioneer in orthopaedic surgery and professor of orthopaedics at the College of Physicians and Surgeons, Columbia University Dr. Whitman remained at the Hospital for Ruptured and Crippled for 40 years—until 1929—when he retired and moved to England. In 1943, after the death of his wife, he returned to the United States and made his home with Mrs. Mollie Whitman, his son's first wife.

It has been said that the progress made in medicine during the first half of the present century was the greatest of any similar period. Many physicians contributed to this advance, each in his particular field. In orthopaedic surgery during the last decade of the 19th century and the first quarter of the present century, Dr. Royal Whitman played a vital and aggressive role. He was one of a small group of physicians in our country who developed and established orthopaedic surgery as an important surgical specialty. Royal Whitman, himself, did much to advance the art and science of orthopaedic surgery, to discard the buckle and strap and to replace expectant treatment with corrective surgery. This change in the attitude of physicians was fostered by the organization, in 1887, of the American Orthopaedic Association, many of whose members were progressive and practiced and preached newer technics of treatment, especially surgical.

Royal Whitman was essentially a clinician. The patient and the outpatient services and the operating room were his workshop. He did not underrate, although he himself did not incline to, laboratory research as we understand it today. Yet, when Dr. Zemansky and Dr. Lippmann proposed the study of Legg-Perthes disease by animal experiment, Dr. Whitman gave them enthusiastic support.

Dr. Whitman's interests lay primarily in the gross and the clinically manifest derangements at the root of his patient's disability and what should be done to remedy them. His research dealt with the practical needs of his patient. Hence, uniformly, his first query in relation to any malady or disability was, "How does it disturb the individual?" This attitude led him to a close analysis of various deformities—the altered anatomy, mechanics and physiology—and the most direct measures for correcting them and improving function. Im-

proved function was the ultimate goal in all therapy. In a letter to me, dated December 20, 1937, Dr. Whitman stated, "I might characterize myself as a perennial student of functional disability and of the most effective means of reducing it."

One of the earliest problems with which Dr. Whitman concerned himself was fracture of the neck of the femur. Prior to his time the treatment of this was desultory and ineffective, actually expectant, with death from an intercurrent infection or pneumonia not far away. In his study of this subject he concluded that the primary requirement was proper alignment and contacting of the fragments and adequate immobilization. He devised the "abduction treatment," whereby the fragments were brought into intimate contact and were retained by the application of a long plaster of Paris spica jacket. This method of treatment created for the patient "the opportunity for repair." He wrote and spoke frequently on this subject at local and national meetings, and succeeded in renewing the interest of the profession in the management of fractured hips. He transformed existing therapeutic apathy into a program of active treatment of a fractured hip that held the prospect of saving life and limb. We all know what a stimulus Dr. Whitman's "abduction treatment" was to orthopaedic surgeons and how many who succeeded him have modified and improved the technic and the results of treatment of fractured hips. But to Royal Whitman belongs the credit for rousing the profession from lethargy and pessimism in the treatment of fractured hips. Dr. Whitman's first article on fractured hips was written in 1890 and his last in 1942.*

Another subject that interested Dr. Whitman early in his career was flat feet or, as he preferred to call the condition, weak feet. His studies of the anatomy of the foot and the leg, the mechanics of the ankle and the foot, and the postural disturbance, both in the resting stage and in walking, constitute a classic. They led him to devise a positive system of correction that included the triad of corrective exercises, appropriate shoes and a corrective foot brace popularly but incorrectly called an arch support. In a letter that Dr. Whitman wrote me, dated December 10, 1937, he stated his belief that his most important contribution was his study of the weak foot begun about 50 years ago. He emphasized that "the weak foot is essentially an improper posture that may be cured by normal activity if the proper relation of the foot and leg is assured."

Dr. Whitman took a particular interest in the postural and the mechanical complicating sequelae of poliomyelitis and performed many of the well-known operations of muscle and tendon transplantation, tenodesis, tenotomy and so forth. During the first quarter of this century, his clinic was one of the largest and his service probably the most active surgically of any in our country. He was specially interested in postpoliomyelitic calcaneus, for which he devised the well-known operation of astragalectomy and backward displacement of the foot. The primary mechanical defect in paralytic calcaneus was the abnormal dorsal flexion of the foot during weight-bearing. This was corrected completely by his operation, which, incidentally, resulted in a symmetric, good-looking foot and a stable ankle. The American Orthopaedic Association selected a committee to study the effects of the various operations used for stabilizing a paralyzed ankle. This committee traveled to many clinics to observe and concluded that the Whitman operation was the most effective. This operation was performed many times at the old Hospital for Ruptured and Crippled by Whitman and his associates and residents, and was continued by all these men. The technic is simple and easily learned. But Whitman's sarcasm discouraged most surgeons except those in his own orbit from learning the technic and doing this most effective operation. In my visit to a very large orthopaedic clinic in 1954, I

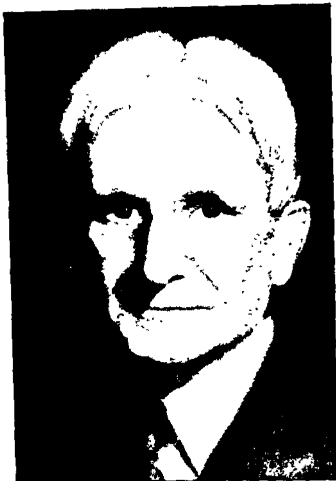
* The Medical Press Circular, Vol. 208, No 5397, Oct. 14, 1942.

found that the men there never had performed a Whitman astragalectomy.

The disability at the hip that resulted from osteoarthritis from whatever cause and old ununited fractures of the femoral neck was a subject to which Dr. Whitman also devoted himself. He devised a reconstruction operation that was relatively simple to perform and gave excellent stability. This operation—the Whitman reconstruction operation—still is used when the chief objective is stability.

During the early decades of this century, manipulative treatment formed an important part of the orthopaedic surgeon's armamentarium. The treatment of club feet was by the use of repeated manipulation and plaster of Paris boots. Although Dr. Whitman was of slender build—I doubt if he weighed more than 125 pounds—he had hands of remarkable strength. He used them so dexterously that there were few, even old, club feet that did not give way to his stretching. The same was true of rigid flat feet. It was not sheer strength that overcame the resistance of the tissues but well-applied and accurately directed pressure and counterpressure. In the use of retentive plaster of Paris dressings Dr. Whitman was an artist. The requisites were adequate smoothly applied sheet cotton followed by a flannel bandage that outlined the parts in the corrected position and then by nicely applied plaster of Paris bandages. A foot had to look like a foot and not a hoof.

His meticulous technic was nowhere better demonstrated than in his surgery. An operation was executed carefully and expeditiously. His knowledge of anatomy was excellent, and he planned his surgical approaches carefully so that the tissues did not suffer undue trauma. As a result, he rarely had an infection in a clean case. He disliked complicated and prolonged procedures, and, when needed, favored a multiple-stage operation. In the early part of the present century, when the art of anesthesia was not as well developed as it is now, speed in surgery was imperative. All Whitman's associates strove to match his care and his dexterity. At one time I announced to him that I had reduced a fractured hip and immobilized the limb in 13½ minutes, which actually was the record up to that time. Dr. Whitman said nothing; praise did not come easily to him. If a man did something especially well, he deserved no commendation; it was expected of him. Several days later Dr. Whitman came down from the operating room and told me that he had just reduced a fractured hip and completed immobilization in *12* minutes.



Dr. Royal Whitman

I have always felt that in surgery Royal Whitman was a pathfinder. He realized the importance and the value of trying out new methods and procedures, and did so frequently. And in the results of these experiments, as well as in all his work, he was his own severest critic.

Dr. Whitman believed in the unity of the

outdoor and the indoor services. Therefore, not only did he make systematic and regular rounds of the wards, but he attended the outpatient clinic, where he examined many new patients and could also observe the results in those who had undergone operative and nonoperative treatment. In this regard he was a hard taskmaster. He demanded of his associates the same strict attendance and attention to detail that he practiced himself. He could not, and did not, countenance lax conduct in the practice of orthopaedic surgery.

As a teacher he was very effective but sometimes exasperating, because he was cynical and sarcastic, especially when he found an assistant to be uninformed. Dr. Whitman read a great deal and had a thorough knowledge not only of the English but also of the German and the French medical literature, and he expected those about him to be equally well informed. In this regard his outdoor clinics on Tuesday, Thursday and Saturday afternoons were very profitable to all the staff members, because during slack intervals he would discuss a great variety of orthopaedic subjects and dispense much valuable information. He was sarcastic with visitors and critical of other clinics. If the visitor was not too sensitive and had been warned in advance, he would enjoy his visit and often learn much; otherwise, sometimes he was offended. Yet, Dr. Whitman never meant to hurt anyone; there was no malice in him. He had only one desire, and that was to further orthopaedics, to teach it, to stimulate others to learn it; but his method was not always the happiest.

Dr. Whitman was outspoken in his opinion of others and their work. He inspired reverence but not friendship. Since he was his own severest critic, he was never concerned with the opinion of others as regards his work. Yet he was very jealous and proud of his membership in the American Orthopaedic Association, of which he was president in 1895, and of his honorary fellowship in the Royal College of Surgeons. He had also been elected an honorary fellow of the Royal Medical Society and an associate of the French Academy of Surgery.

Dr. Whitman had a superb command of the English language, but he was not inclined to address big audiences. At medical meet- ings he participated liberally in the discus- sions and related his experiences freely. He contributed a great deal to the literature of orthopaedics, but his greatest contribution was his textbook on orthopaedics, which went through 14 editions and was a master piece of information. It was clear, conc and adequately illustrated. Dr. Whitman employed the shortest phrase and the fe words possible to describe his findings thoughts. He eschewed big words, long s tences and, especially, foreign expres when English sufficed. In the use of English language he was a purist. instance, the word *cast*, which mea mold, or impression, was always use that sense and not as it has become po to apply it, to any plaster of Paris dres This is an example of the care with w he chose his words.

Of Dr. Whitman's social life and hab like his other associates, knew very litt was a reserved man, even at social func He read a great deal. He preferred w to riding: he always walked at a mo pace; he never hurried. He seemed ne tire. He was an expert golfer. He pl his life: his rounds began at 8:30 A.M woe betide the assistant who was l time; he would get the sharp edge tongue. The outdoor clinic began a P.M., and we could have set our w by his entrance. At 3:00 P.M., the termination of the clinic, Dr. W would leave, even if it meant ending versation abruptly.

Such is my recollection of Royal man, the most accomplished orth surgeon of his day in our country, teacher, an expert surgeon, a stim example to his associates and a be to orthopaedic surgery and to hum

Section I

THE FOOT

2

The Skeletal Development of the Foot*

RONAN O'RAHILLY, M.D., ERNEST GARDNER, M.D., AND
D. J. GRAY, PH.D.†

INITIAL DEVELOPMENT OF THE LOWER LIMB

As has been explained in a previous issue,[27] the embryonic period proper, according to the usage adopted at the Department of Embryology, Carnegie Institution of Washington, comprises the first 7 postovulatory weeks. Furthermore, this period has been divided into 23 stages.

The limbs first appear as minute buds in embryos of 4 postovulatory weeks. The lower limb buds, which appear very slightly later than the upper, are seen in embryos of about 3 to 6 mm. in length (Stage 13). Each limb bud elongates and develops in proximodistal sequence; e.g., the thigh appears before the foot. The latter is first seen at 4½ weeks (Stage 15). The skeleton (in the form of cartilage) and the muscles become visible within a few days, and, shortly afterward, the toes can be observed (Stages 18-19). The changing configuration of the developing limbs has been studied in considerable detail.[13,24]

An ectodermal thickening appears on the ventral aspect of the lower limb bud almost as soon (Stage 13) as the bud is visible.[24] A few days later (Stage 15), the lateral part of this thickening forms an ectodermal ridge that disappears within a week (Stage 19). The ridge is a site of great metabolic activity, as judged by histochemical examination. The importance of this ridge has been established experimentally in the case of the chick embryo. The mesoderm at the apex of the limb bud progressively lays down the future limb components in proximodistal sequence and in their future spatial pattern; this process is dependent on the ectodermal ridge. The ectodermal ridge is significant in mammals also. These conclusions are important in the elucidation of many developmental anomalies of the limbs.[21]

The skeletal elements of the limbs are seen first as mesodermal condensations, which soon chondrify in a definite order.[26]

Ossification, in the form of a periosteal collar in tubular bones, occurs subsequently. In the femur and the tibia, and sometimes in the fibula, ossification commences during the embryonic period proper. Vascular invasion of these skeletal elements by one or more periosteal buds and the establishment of centers of endochondral ossification take place during the fetal period. Vascular invasion of the tarsals occurs during the fetal period, whereas endochondral ossification does not begin in some tarsals until after birth.

The various features in the embryonic development of the lower limb are summarized in Table 1. Some of the details of the chondrification and the ossification will now be presented.

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* The embryologic work of the authors has been supported by Research Grants A-532 and A-1644 from the National Institute of Arthritis and Metabolic Diseases of the National Institutes of Health, U S Public Health Service.

† Departments of Anatomy, Wayne State University College of Medicine, Detroit, Mich., and Stanford University School of Medicine, Stanford, Calif.

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TABLE 1. EARLY DEVELOPMENT OF LOWER LIMB

FEATURE	STAGE	MM.	POSTOVULATORY WEEKS	AUTHORS
Lower limb bud	13	3.0-6 0	4	Streeter (1945)
Foot plate	15	6 0-11.0	4½	Streeter (1948)
Ectodermal ridge	15-18	6.0-18 0	4½-5	O'Rahilly, Gardner and Gray (1956)
Mesenchymal hip bone ..	16	9	5	Bardeen (1905)
Mesenchymal femur, tibia, fibula	17	8.6-14.5	5	O'Rahilly, Gray and Gardner (1957)
Mesenchymal foot	17-18	8.6-18 0	5	O'Rahilly, Gray and Gardner (1957)
Chondrifying femur, tibia, fibula	17-18	8.6-18.0	5	O'Rahilly, Gray and Gardner (1957)
Chondrifying hip bone ..	18	12	5	Bardeen (1905)
Chondrifying foot	18-23+	11.7-32.2	5-7	O'Rahilly, Gray and Gardner (1957)
Mesenchymal patella	20	18.5-25.0	6	O'Rahilly, Gray and Gardner (1957)
Chondrifying patella	21	19.0-26.4	6	O'Rahilly, Gray and Gardner (1957)
Ossifying femur, tibia ...	22-23	23.0-32.2	6½-7	O'Rahilly, Gray and Gardner (1957)
Cavitation in hip	?	28	7	Gardner and Gray (1950)
Cavitation in knee	?	30	7	Gray and Gardner (1950)
Cavitation in ankle	?	30	7	Gardner, Gray and O'Rahilly (1959)
Ossifying fibula	?	29-35	7	Noback and Robertson (1951)
Cavitation in foot	?	30-?	7-?	Gardner, Gray and O'Rahilly (1959)

PHASE OF CHONDRIFICATION IN THE FOOT

The tarsus can first be distinguished as condensed mesenchyme at 5 postovulatory weeks of age (Stages 17-18). Within a few days (Stages 18-19), the individual tarsals begin to chondrify in a definite sequence.

The metatarsals begin to chondrify at the same time, 5 weeks (Stages 18-19), as the tarsals During the next week (Stages 20-23), the 3 rows of phalanges commence to chondrify in proximodistal sequence.[26]

A large number of accessory skeletal elements have been described for the foot.[22] Some of these have been observed in a cartilaginous state in embryos and fetuses, and some may develop independent ossific centers in postnatal life. We have seen an os intermetatarsale (45 mm C.R.) and an os paracuneiforme (122 mm. C.R) in fetuses. It is generally agreed that the incidence of accessoria in the adult is considerably higher in the tarsus than in the carpus.

The best-known example of bipartition in the tarsus is that of the medial cuneiform.[2] An example in an embryo (18 mm) has been observed by us.

So-called fusions—e.g., talocalcanean and calcaneonavicular—are of considerable clinical interest. Instances of the former have been found in an embryo (28 mm. C.R.) and in fetuses (e.g., at 73 mm. C.R.), and the latter condition has been seen in fetuses by us.

Symphalangia, or so-called fusion between phalanges, is found frequently in adults in the fifth toe between the middle and the distal phalanges.[27,33,34] This condition is observed in about half of all fetuses from 10 menstrual weeks onward.[7]

The digital sesamoids first appear during intra-uterine life, slightly later than the other ("canonical") skeletal elements. Sometimes those of the foot may begin to chondrify as early as 7 weeks, and their distribution and frequency resemble closely those of the adult.[7]

The initial phase in the development of the synovial joints—i.e , the formation of "interzones" between the various skeletal elements—takes place during the last week of the embryonic period proper (Fig. 1).[7] The lower end of the fibula is very closely related to the calcaneus during the seventh



FIG. 1. Horizontal section of left foot of an embryo aged 7 postovulatory weeks (28 mm, C.R., No. 1465). Portions of the medial malleolus, the talus and the cuboid are visible in the lower part of the photomicrograph. Parts of the navicular, the cuboid, the three cuneiforms and the second to the fifth metatarsals can be identified.

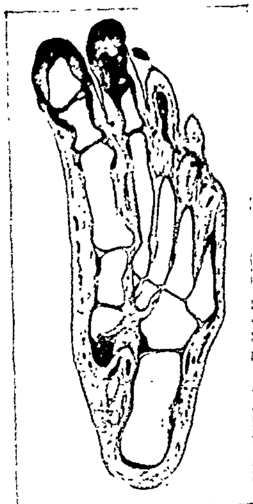


FIG. 2. Horizontal section of left foot of a fetus aged about 10 menstrual weeks (45 mm., C.R., No. 1531). The calcaneus and the cuboid are visible in the lower part of the photomicrograph. Portions of the navicular, the three cuneiforms and all five metatarsals can be identified. Note the cavity of the calcaneocuboid joint.

week (Stages 20-23). Cavitation commences in most joints of the foot during the first 2 weeks of the fetal period (Fig. 2).

It should be emphasized that the phase of initial chondrification and preliminary joint formation in the foot takes place within the embryonic period proper (Fig. 1). Generally, all the "canonical" elements of the foot have begun to chondrify by 7 postovulatory weeks; therefore, the number and the arrangement of these elements is determined prior to this time. It follows that anomalies in which the number of the skeletal elements is increased arise very early in intra-uterine life and that the causative factors must act before 7 weeks of development. An example of such an anomaly is a medicolegal case that was characterized by partial tibial hemimelia associated with heptadactylia.[23]

PHASE OF PRENATAL OSSIFICATION IN THE FOOT

The period during which ossification commences in the foot extends from the end of the embryonic period proper to postnatal life.

As in the case of the hand, generally the

TABLE 2. C.R. LENGTHS AND TIMES DURING WHICH BONE COLLARS AND VASCULAR INVASION OF THE SHAFT FIRST OCCUR IN THE METATARSALS AND THE PHALANGES OF THE FOOT[7]

	Bone Collar		Vascular Invasion	
	Mm.	Menstrual Weeks	Mm.	Menstrual Weeks
Metatarsals 1-5	39-55	9-11	60-78	11-12
Proximal phalanges 1-5	49-95	10-14	85-156	13-19
Middle phalanges 2-4	122-359	15-birth	156-373	19-birth
Distal phalanges 1-5	30-308	9-36	60-308	11-36

first elements to show signs of ossification in the foot are the distal phalanges. That of the big toe may begin as early as 7 weeks. Moreover, the peculiar mode of ossification of these phalanges is similar in both the hand and the foot.[7,9] Intramembranous ossification and endochondral ossification commence at the tip of a distal phalanx instead of at the center of the shaft, as in other tubular bones. These processes then advance in only one direction; i.e., proximally. The tuberosity of the distal phalanx is formed by further development of the area of intramembranous bone formation.

TABLE 3. COMPARISON BETWEEN PRENATAL SKELETAL DEVELOPMENT OF THE 3RD FINGER AND THAT OF THE 3RD TOE

	3rd Finger	3rd Toe
	Stage	Stage
Chondrification		
Metacarpal or metatarsal	17-18	18
Proximal phalanx	18	19-20
Middle phalanx	19-20	21
Distal phalanx	21	23
Bone Collar	mm c.r.	mm. c.r.
Metacarpal or metatarsal	30-39	39-55
Proximal phalanx	43-49	49-95
Middle phalanx	56-65	150-308
Distal phalanx	26-30	43-55
Vascular Invasion		
Metacarpal or metatarsal	43-61	60-69
Proximal phalanx	65-83	85-122
Middle phalanx	85-110	235-308
Distal phalanx	60-110	60-180

During the fetal period, bone collars may be discerned in each of the metatarsals and the phalanges some little time (1-5 weeks) before the appearance of the periosteal buds; hence, before the centers of endochondral ossification are formed. The vascular invasions that herald the approach of the ossification centers (Table 2) appear in the metatarsals and the phalanges between 9 menstrual weeks and birth.

The relative delay in the prenatal skeletal development of the foot as compared with that of the hand can be assessed by comparing a radiogram of the hand with one of the corresponding foot.[18] A further illustration of the "lag" can be seen by comparing the progress of events in the third toe with that in the third finger (Table 3).

Unlike the carpus, ossification begins in some of the tarsals before birth. A seemingly inconstant area of ossification, described as perichondral[11] or parachondral,[12] may be seen (Fig. 3) as early as 13 menstrual weeks (Table 4, periosteal ossification). It is lateral in position, appearing in a groove between the lateral process of the tuber (lateral tubercle) behind and the peroneal process in front. Thus, it is behind and not, as commonly stated, at the site of the peroneal trochlea or tubercle. As in the case of a long bone, the perichondral or periosteal bone formation is followed by the appearance of an endochondral center Apparently two such centers may sometimes appear. At any rate, double centers have been illustrated in infants by several writers.[3,30]

TABLE 4. C.R. LENGTHS AND TIMES DURING WHICH OSSIFICATION MAY FIRST OCCUR PRENATALLY IN THE TARSALS[7]

	PERIOSTEAL OSSIFICATION		ENDOCHONDRAL OSSIFICATION	
	MM.	LUNAR MONTH	MM.	LUNAR MONTH
Calcaneus	93	4th	150-180	5th
Talus	—	—	253 on	8th-after birth
Cuboid	—	—	359 on	10th-after birth

The second tarsal to exhibit bone formation is the talus, during the last trimester of intra-uterine life. However, an ossific center for the talus is not always present at birth.[4] It has been claimed that the talus "appears to arise originally from several ossification points, which are united rapidly into a uniform center and, therefore, easily escape observation."[29]

The cuboid sometimes begins to ossify before birth. Its center is said to develop from several foci.[11]

The lateral cuneiform rarely presents a center in the newborn.[4]

PHASE OF POSTNATAL OSSIFICATION IN THE FOOT

Centers appear during infancy in the 3 cuneiforms and the navicular (Table 5). The medial cuneiform and the navicular may



FIG. 3. Sagittal section through right calcaneus of fetus aged approximately 16 menstrual weeks (132 mm., C.R., No. 1235). Note the periosteal bone formation (arrow). Several small "cartilage canals" are visible in the calcaneus.

TABLE 5. TIMES OF APPEARANCE OF POSTNATAL OSSIFIC CENTERS IN THE FOOT. MEDIAN AGES IN YEARS[5,14,17]

Bone	*Appearance*		*Complete Radiographic Fusion*	
	Female	Male	Female	Male
Tibia, distal end	1/3	1/3	15	16
Fibula, distal end	3/4	1	15	16
Tuber calcanei	5	7-8	14	15
Top of tuber	11	13	14	?
Talus, lateral tubercle of posterior process	8	10	10	12
Lateral cuneiform	1/3	1/3		
Medial cuneiform	1	2		
Intermediate cuneiform	2	2		
Navicular	2	3		
Metatarsal epiphyses	2-4	2-4	15	16
Tuberosity of 5th metatarsal	10	12	13	14
Phalangeal epiphyses	1-4	1-4	14	15
Sesamoids	9	12		

A radiographic atlas of the postnatal skeletal development of the foot is now in press It will be along lines similar to the *Radiographic Atlas of Skeletal Development of the Hand and Wrist,* by W. W. Greulich and S. I. Pyle, ed. 2, Stanford Univ. Press, 1959.

each develop from 2 centers. Epiphysial centers appear in the metatarsals and the phalanges during infancy and early childhood. Generally, these epiphysial centers appear at the bases of the elements, with the exception of the second to the fifth metatarsals, where they usually develop at the heads. Frequently, the epiphysial centers are multiple.[28] The centers in the bases of the middle phalanges of the third to the fifth toes may be absent. Irregularities in the ossific pattern are not uncommon in the foot, and bizarre appearances are found sometimes.[20]

Secondary centers appear during childhood in the tuber calcanei, the lateral tubercle of the posterior process (posterior tubercle) of the talus and the tuberosity of the fifth metatarsal. An additional center is found in the top of the tuber calcanei about a year or two before puberty.[10] It has been claimed that frequently a center can be found in the medial tubercle of the posterior process of the talus[16] and another in the anterior portion of the medial cuneiform.[15]

SUMMARY

An account of the skeletal development of the foot is presented, the prenatal findings being based on our research, the postnatal findings being summarized from the literature.

The lower limb buds appear at 4 postovulatory weeks (Stage 13). A few days later, an important ectodermal ridge (Stage 15) and a skeletomuscular condensation (Stage 16) are seen.

The various skeletal elements of the foot are distinguished as condensed mesenchyme at 5 postovulatory weeks (Stages 17-18). Chondrification takes place in a definite sequence during the 6th and the 7th weeks (Stages 18-23).

It is emphasized that the number and the arrangement of the "canonical" skeletal elements of the foot are determined prior to 7 postovulatory weeks of intra-uterine life

The sesamoids of the foot may sometimes begin to chondrify as early as 7 postovulatory weeks Their distribution and frequency resemble closely those of the adult.

The tip of the distal phalanx of the big toe may begin to ossify as early as 7 post-ovulatory weeks. The vascular invasions that precede the appearance of the endochondral ossific centers are found in the metatarsals and the phalanges generally between 11 menstrual weeks and birth. However, bone collars can be detected 1 to 5 weeks earlier.

Ossification takes place in the tarsus in a more or less definite sequence during the latter two thirds of intra-uterine life and during infancy. The metatarsal and the phalangeal epiphysial centers appear during early childhood. Radiographic fusion of these last-mentioned centers occurs shortly after puberty.

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Le Disveloppamento Skeletic del Pede

Summario in Interlingua

Es presentate un description del disveloppamento skeletic del pede. In isto, le constatationes prenatal es basate super le recercas personal del autores, e le constatationes postnatal es summarisate ab le litteratura.

Le gemmas del extremitates inferior appare el etate postovulatori de 4 septimanas (stadio 13). Alicun dies plus tarde, un importante cresta ectodermal (stadio 15) e un condensation skeletomuscular (stadio 16) es visibile.

Le varie elementos skeletic del pede es distinguibile como mesenchyma condensate a un etate postovulatori de 5 septimanas (stadios 17 a 18). Chondrification occurre in un definite sequentia durante le sexte e le septime septimana (stadios 18 a 23).

Es sublineate que le numero e le disposition del "canonic" elementos skeletic del pede es determinate ante le etate postovulatori de 7 septimanas in le vita intra-uterin.

In certe casos le ossos sesamoide del pede comencia jam lor chondrification a un etate postovulatori de non plus que 7 septimanas. Lor distribution e lor frequentia resimila fortemente le distribution e le frequentia del ossos sesamoide in adultos.

Le puncta del phalange distal del halluce comencia a vices su ossification jam 7 septimanas post le ovulation. Le invasiones vascular que precede le apparition del centros ossific endochondral es generalmente trovate in le metatarsales e le phalanges inter 11 septimanas postmenstrual e le parturition. Tamen, bandas periosteal es detegibile inter 1 e 5 septimanas plus tosto.

Ossification occurre in le tarso in un plus o minus definite sequentia durante le secunde e ultime tertios del vita intra-uterine e durante le infantia. Le centros epiphyseal metatarsal e phalangee appare tosto in le pueritia. Le fusion de iste centros es radiographicamente observabile brevemente post le pubertate.

3

The Trabecular Patterns of the Normal Foot*

MICHAEL C. HALL, F.R.C.S.(C.)†

The trabecular system of a bone was shown by Koch[3] to be one that gives maximum strength from the use of a minimal amount of material. The pattern demonstrates the lines of force in a bone, but force is not necessary for their development, since the standard patterns will be found in explanted bones grown in vitro, as Fell[1] demonstrated. However, these patterns will change if the lines of force are changed and give an indication of the deformity present (Steindler[4]).

The engineering principles of the neck of the femur have been examined in great detail; therefore, its trabecular pattern is well understood. However, that of the foot seems to have been described only briefly. It is believed that a study of this nature allows a better understanding of the lines of force in a bone or composite of bones such as the foot, and that in this way the static and dynamic clinical problems of their structure may be followed more readily. On the other hand, some may believe that it is strictly an academic exercise, in which case one can only plead that at least the patterns described are pleasing to the eye.

None of the long-standing arguments in regard to arches, points of pressure, etc., will be pursued, but some of the features to be described are self-evident in such regard.

The material used was obtained from the dissecting room. In no case had the dissection been carried into the joints, and all the feet appeared to be free of deformity. Of necessity, these are the feet of older people, and some osteoporosis will be present. This is not believed to have altered the patterns and is manifested, if at all, in the less important secondary group of trabeculae rather than in the primary group.

Twelve feet were examined by sawing them into ¼-inch slabs in a coronal plane (4 feet), or in a transverse plane (4 feet), or dividing them between the digital rays (4 feet). Apart from minor differences described, the appearances were the same.

DESCRIPTION

The lines of the trabeculae may be followed down through the tibia into the talus and through the remainder of the foot.

In the sagittal sections of the tibia, the trabeculae are seen to radiate at right angles from the lower articular surface up the shaft (Fig. 8). At about 1 inch above the articular surface, the central trabeculae begin to veer to the nearest cortex to allow the formation of the medullary cavity.

In the coronal sections, the same general pattern obtains, but the veering to the side occurs almost from the level of the joint, giving a "V" appearance (Fig. 4).

At the apposing articular surfaces of the talus and the tibia, the major trabeculae are reinforced by many minor ones parallel to them and a few running in an arc parallel to the articular surface, as a response to the flattening of that surface during weight-bearing (Fig. 8).

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FIGS. 1 to 4. Coronal sections FIG. 1. Heads of metatarsals. Note vertical trabeculae in each.

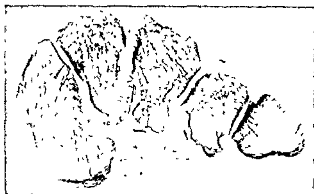


FIG. 2. Cuneiforms, fourth and fifth metatarsal bases.

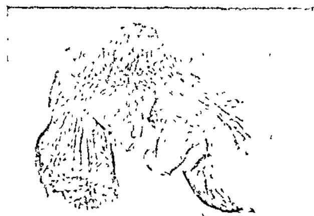


FIG. 3 Navicular, cuneiforms, cuboid.



FIG. 4. Center of body of talus, showing sustentaculum tali and formation of medullary cavity of tibia.

In sagittal sections of the upper subcortical area of the body of the talus, the trabecular pattern is not so obvious. There is a confluence of the trabeculae of both the posterior and the anterior pillars of the foot, and, although the trabeculae of the posterior pillar may be followed through the confluence, it is difficult to follow those of the anterior pillar (Figs. 8 & 9). In coronal sections taken through the talus, the trabeculae posteriorly may readily be followed down from the more central section of the upper cortex of the talus through the calcaneum (Fig 4). In horizontal sections, the anterior trabeculae may be followed from the body through the neck and the head of the talus (Fig. 6). Thus it is seen that what appears on the sagittal section to be an unorganized trabecular network is, in fact, a confluence of the trabeculae from the anterior and the posterior pillars that pass, uninterrupted, through the body of the talus.

On the medial side, the trabeculae of the posterior pillar are divided by the canalis tarsi, terminating in two groups, one in front and one behind the canalis. The trabeculae beneath the anterior talocalcaneal joint meet its surface at right angles. They are short and soon lost, suggesting that actually little weight is transmitted through this joint (Fig. 9). However, they can be followed curving



Figs. 5 to 7. Horizontal sections. Fig. 5. Medial malleolus with groove for tibialis posterior; wedge-shaped body of talus, wider anteriorly; lateral malleolus with groove for peroneal tendons.



Fig. 6. Body and neck of talus.

forward, sometimes into the neck of the talus (Fig. 10); this will be discussed later.

In the calcaneum, beneath the canalis tarsi, there is a thin shell of relatively dense cortical bone, but beneath this area little trabecular bone is found

Behind the canalis tarsi the trabeculae run downward and backward through the waist of the calcaneum as thick coarse bundles, becoming finer and more numerous

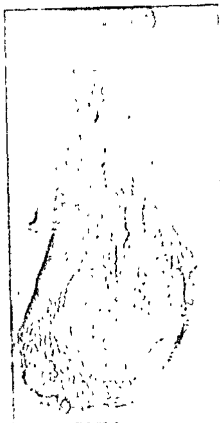
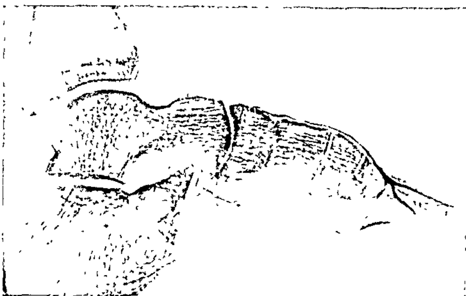


Fig. 7. Calcaneum.

as they pass backward to fan out to the entire posterior surface, reaching inferiorly slightly in front of the posterior tubercles (Fig. 11). In horizontal (Fig. 7) sections, this posterior column is found to be very much stronger on the medial side than on the lateral.

More laterally, at the depression between the posterior articular surface and the beak of the calcaneum (Fig. 11), there is a dense aggregation of cortical bone in appearance resembling the waist of a wheatsheaf. Trabeculae are seen radiating from this point forward to the area of the anterior calcaneal surface that articulates with the cuboid, arching backward and downward to join the posterior pillar running to the lower posterior surface of the calcaneum, and a few trabeculae running at right angles to the long axis of the bone to the anterior tubercle. Between the posterior pillar and the short supporting trabeculae of the calcaneal surface lies a large area almost devoid of trabeculae, known as the foramen calcanei.



FIGS. 8 to 11. Sagittal sections. FIG. 8. First metatarsal segment.

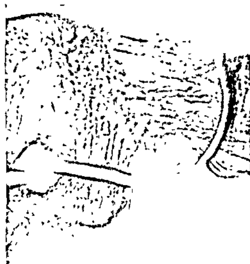


FIG. 9 Detail of anterior talocalcaneal joint



FIG. 10. Detail of anterior talocalcaneal joint.

The anterior pillar may be followed from the body of the talus to the heads of the metatarsals The trabeculae in the neck of the talus may be followed superiorly from beneath the upper surface of the body and through the upper region of the neck to blend with the others and end at the anterior articular surface of the head at right angles to this surface. In horizontal sections they are seen running parallel to the axis of the neck and the head (Fig 6).

In the sagittal sections of the lower part of the neck of the talus, it is possible to follow trabeculae into it from two areas of the calcaneum. As mentioned previously, the anterior area of the talocalcaneal articulation has trabeculae running at right angles to its surface, both in the calcaneum and in the talus. Those in the talus either will continue vertically upward to end in the articular surface at the ankle joint or arch forward to join the trabeculae of the anterior pillar, forming thus an arch that may be followed from the heads of the metatarsals to the heel (Fig 10). This arch through the anterior joint is not always seen in the sagittal sections. Its demonstration does not depend on the site of section but on an individual variation from foot to foot. Harris[2] has

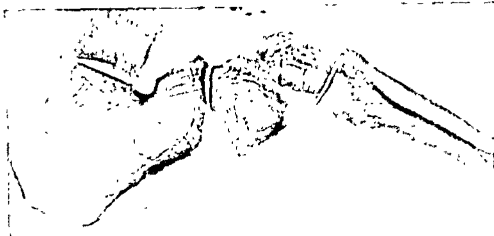


FIG. 11. Fourth and fifth metatarsal segments.

shown the variations that will occur in the anterior group of the subtalar joint complex, and on examining a number of these bones it is easy to confirm that there is a considerable variation in the presence or the absence of this part of the complex and in the relative sizes of those that are found. Therefore, the direction that the trabeculae take from the anterior articular surface of the talus may depend on the degree of development of this joint.

The trabeculae may be followed through the head of the talus into the navicular, the cuneiforms and the bases of the three medial metatarsals as a parallel, evenly distributed group. From the bases they continue to run parallel to each other until they blend with the cortex. At the necks of the metatarsals they again become apparent, radiating out to the cortex of the head but passing predominantly to the lower weight-bearing surface A similar pattern is found in the phalanges, becoming less distinct in them from proximal to distal phalanx.

On the lateral side of the anterior pillar, the trabeculae are followed not from the talus but from the calcaneum (Fig. 11). The anterior of the radiations from the dense region at the anterior edge of the posterior articular area fans out to meet the anterior end of the calcaneum at right angles. It is reinforced below by some trabeculae parallel to the lower surface of the calcaneum. On the lateral side of the cuboid, the trabeculae may all be followed into the bases of the 4th and the 5th metatarsals, but on the medial side a group passes steeply downward to the inferior ridge to which the plantar ligaments are attached.

Successive coronal sections through the forefoot demonstrate the transverse arch of the foot (Figs. 2 & 3). They show a complete arch with pillars on either side and a gently curving central region, and not one half of an arch requiring that of the other foot to complete it. The bone is much stronger at the superior surface of the arch than at the inferior, as would be expected. Both the longitudinal and the transverse trabeculae contribute to this.

A group of trabeculae more obviously concerned with movement than with weight-bearing are found in the posterior half of the calcaneum (Fig. 11). They run in a curved fashion round the back of the heel as a dense bundle resisting the deforming influence of the tendoachillis above and the plantar fascia below. The two form in such animals as the rabbit a single structure passing round a pulley made by the posterior surface of the calcaneum. There is a less compact radiation in the entire posterior third of the calcaneum fanning from its posterior surface to aggregate in the cortical bone of its lower surface. This will resist *not only the deforming forces of the* posterior structures but also the flattening forces exerted on the calcaneum in standing.

The medial and the lateral malleoli are shown on both horizontal (Fig. 5) and co-

ronal (Fig. 4) sections to have a double trabecular system. Peripherally, a bundle of trabeculae follow in the subcortical region the curves of the cortex. Centrally, trabeculae are seen radiating from both articular and nonarticular surfaces of the malleoli. The peripheral group are in response to the pull of the ligaments of the ankle and thus are comparable with the group at the back of the calcaneum. The central group are in response to the side-to-side shift of the talus in its mortice, demonstrated at the articular surface, and the compression of tendons in pulleys demonstrated in the nonarticular surface.

SUMMARY

The trabecular patterns of the foot show major medial and lateral arches that can be traced longitudinally through the length of the foot. That on the medial side passes from the calcaneum through the talus and distally; that on the lateral side, through the cuboid, avoiding the talus.

There may be an additional medial arch complete through the anterior subtalar joint.

The transverse arch is seen to be a complete arch with both medial and lateral pillars.

Other smaller patterns, due to the static forces of posture or dynamic forces of tendons, ligaments and movement, are described.

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Le Configurationes Trabecular del Pede Normal

Summario in Interlingua

Trabeculas in osso servi a impartir un maximo de fortia a un minimo de material. Un studio del configurationes del trabeculas in un osso o un complexo de ossos como per exemplo le pede demonstra le lineas de fortia in ille osso o complexo de ossos. Un tal studio es de adjuta in obtener un melior comprension del fortias interessate.

Dece-duo pedes esseva sectionate in planos transverse, coronal, e sagittal, e le resultante plattas de osso esseva roentgenographate.

Es monstrate que le trabeculas pote esser sequite continuemente ab le tibia: a transverso le corpore e le cervice del talo a in le metatarsales al latere medial del pede; a transverso le talo inferiormente a in le calcaneo; e ab le calcaneo lateralmente a in le cuboide e le metatarsales. Il occurre un variation al articulation sub-talar anterior, a transverso le qual un complete arco de trabeculas pote passar, dependente del peso que es supportate a iste articulation.

Sectiones a transverso le articulation talocrural demonstra separate gruppos de trabeculas in le malleolos, in responsa al fortia del tendines, ligamentos, e movimento lateral del talo in su base.

Sectiones coronal a transverso le pede intermediari e anterior monstra un arco con pilares complete tanto medial- como etiam lateralmente

4

Congenital Anomalies of the Tarsal Bone

Fred W. Hark, M.D.*

Frequently, the end-result of tarsal bone anomalies is a rigid static flat foot. Until recently, the etiology of this type of foot was attributed to conditions that were the result of the entity, as the rigidity or the spasticity of the peronei muscles. At present it is felt that most often the etiology is due to bony anomalies or arthritic conditions and that the therapy should be directed at the tarsal regions of the extremity.

My interest in the problem was aroused by a 6-year-old girl who walked with comfort only when the foot was supported in valgus with an outer wedge under the heel. On inspection, this foot appeared to be normal. On palpation, there was an unusual prominence about 1 cm. posterior to the internal malleolus. It was not tender to palpation but was the site of her discomfort after walking. A bridge, fibrous or bony, across the sustentaculum tali joint was suspected.

At this time we had no clinical recordings of the etiology of this type of lesion. Anatomists Dwight[6] and Laidlow[11] have discussed anomalies in this area. Briefly, the posterior border of the astragalus is divided by the groove of the flexor hallucis longus. The part lateral to the tendon groove is in the form of a process. It may be short or long If it is long, it is known as Stieda's process. It is at this point that the os trigonum is found. The posterior border medial to the flexor hallucis groove usually is undeveloped. Occasionally, it has developed into a sort of hook and might be classified as a l pulley. It has no function.

At the posterior border of sustentac tali there may be found a bone known a os sustentaculi. According to Dwight, I ner has seen it twice as a distinct bone nected by fibrocartilage or fibrous tissu the posteromedial end of the sustentac tali. He has recognized it several time being fused to the sustentaculum. Dw comments that it has no importance ex as being concerned in a fusion between medial posterior border of the astrag and the os calcis through the sustenta He states further that a fusion would difficult to show in a roentgenogram. It

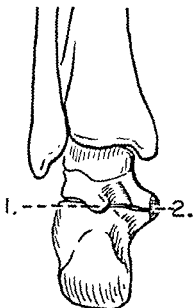


Fig 1. (1) Stieda's process. (2) The enlarged posterior border of talus and sustentaculum of os calcis with fibrosis across the superficial edge.

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in this area that our 6-year-old's problem was developing.

Fusions between the os calcis and the scaphoid are also pointed out by anatomists. As was hinted above, in most instances fusions are through the medium of a third bone. The os calcaneus secondarius is credited by Slomann[13] as performing that function across this joint.

There are fusions both fibrous and bony described between the talus and the navicular and between the os calcis and the cuboid.

Clinically, in the twenties there were numerous reports on fusions between the calcaneus and the navicular.[3,7,9] However, talocalcaneal[5,7,12] fusions were not reported much before the late thirties or the early forties.

There are reports on fusions between the calcaneous and the cuboid, and the talus and the navicular,[2] and the conclusion[4] usually is that they probably have little clinical significance. On the other hand, congenital abnormalities about the subastragaloid and the calcaneoscaphoid joints frequently were symptomatic.

In connection with lesions about the subastragaloid joint, if the patient is less than 7 or 8 years of age, there is pain or discomfort on walking, and on palpation there may be tenderness at the site of complaint. There is little or no muscle spasm, but motion in the subastragaloid joint is more or less limited. Children a few years older also present peroneal muscle spasm and valgus deformity of the foot. Such patients usually attribute their disability to a walk of more than average effort or duration, as a hunting trip in deep snow or the first boy-scout hike in the spring. The author has observed patients pass from one phase into the other

An 8-year-old girl presented herself at the St. Luke's Clinic because of moderately flat feet. With effort she could hold her arches up, but she stated that it was not comfortable. On examination the enlargement behind the internal malleolus was visually noticeable and palpable but not painful. Removal of the anomaly was advised but refused. In the course of 2 years, in spite of supportive shoe work the valgus, or pronation, of both feet increased; the peronei tendons became tense and fixed, and the patient lost the power of supination even passively. This course has been seen to unfold in 2 patients, both in their early teens.

I used to feel that to get relief from a spastic static flat foot a fusion of the involved joints was required until one day a 6-year-old boy was brought in walking with a boardlike gait, both ankles in valgus and the peronei tendons standing out like bowstrings. There were no abnormal bony prominences palpable. There was too much pain on motion to test which joints might be the seat of the lesion. The idea of fusing two ankles in a 6-year-old did not appeal to me, and the child was placed in short-leg plaster casts that were changed frequently to take up the slack as the peronei relaxed. Eight months in plaster cured these feet. No other joints in the body were involved, and yet I believe that these feet come under the classification of arthritic feet. Etiologically, Harris has arthritis as Group 3 in his classification of the rigid flat foot. An outstanding feature in this case was the muscle spasm. Peroneal muscle spasm has not been observed in this clinic at 6 years of age in the type of foot under discussion, and it may be the clue in differential diagnosis.

The diagnosis of a fibrous or bony bridge across a tarsal joint will hinge on the palpation of a bony prominence, limitation of mobility of the joints in question and its demonstration in the roentgenogram.

In the case of the anomaly across the subtalar joints, it is usually at the posterior limit of the sustentacular joint and is easily palpable. No other areas of bridging have come to my attention Theoretically, a bridge could form through fusion around the os trigonum. According to Harris,[7] a roentgenogram would be helpful in that it would show obliteration of the sustentaculum tali

The prominence itself is not great enough to stand out as such in the roentgenogram.

In regard to radiographing this lesion, Harris reproduced one of Livingston's illustrations showing the foot in calcaneus in relation to the tibia, with the sole of the foot squarely on the x-ray cassette. It is recommended that the rays be directed at 35°, 40° and 45° to the plate in the anteroposterior plane of the leg. One view then should pass through the sustentacular joint if there were a clear one. I have not been able to get a roentgenogram of this lesion that would reproduce in a photograph illustrating the anomaly clearly. On the other hand, roentgenograms clearly show the bridge across the calcaneonavicular joint, it is ossified. It cannot be palpated; it can only be suspected when one feels a peculiar lack of mobility on grasping this region of the foot between thumb and forefinger. This anomaly has also been found several times in connection with the rocker-foot deformity.

The treatment followed in the younger children with the talocalcaneal anomaly was resection. In the first case the bony prominence and most of the sustentaculum tali process were resected. On examining the specimen it was noted that there was fibrosis only across the superficial part of the joint and that the adjoining surfaces deeper in were covered with cartilage of good depth. Therefore, in the succeeding 2 cases the prominence was exposed through a curved incision behind the medial malleolus and planed down with a chisel until a good joint space lined with cartilage came into view. The clinical course of these 3 cases was uneventful. The period of observation was 2 years.

Clinicians and anatomists state that after the age of 11 the union in the bridges is



Fig. 2 Not only is there a large os tibiale externum but the tuberosity of navicular is large. This is moved back to the broken line. This enlargement may be a factor in holding the forefoot in valgus. One often sees a valgus foot with a navicular of this shape but no accessory ossicle. Kidner attributed the valgus to the mechanical presence of the accessory ossicle.

bony. All teen-age cases were treated by a triple arthrodesis. The triple arthrodesis was also practiced in connection with the calcaneonavicular bridge. Resection of this bridge has not been successful, possibly because it is an area where several tarsal bones touch, and it is not practical to make an exposure that shows the dorsal and the plantar contours of this area; hence it is difficult to judge what constitutes an adequate resection.

By triple arthrodesis is meant a fusion of the talonavicular, the calcaneocuboid and the talocalcaneal or subtalar joints as described by Ryerson.

Kidner's[10] "prehallux or accessory scaphoid" also gives a symptomatic syndrome. A 56-year-old woman consulted me because of a painful foot for 46 years. She presented an ankle valgus somewhat fixed, peronei tendons tense and prominent under the fibula. The quite prominent tuberosity of the navicular was tender to touch. There was no mobility in the subtalar joint. She walked with a boardlike gait. The roentgenogram (Fig. 2) showed a tuberosity of the navicular that was enlarged and irregular in shape. In contact with it there is a large os tibiale externum. It lies more under the head of the talus than is customary for this ossicle. This patient stated that the foot began troubling her at the age of 10. She was put in a cast for several months, followed by a brace for a number of years, and ended up with a specially built shoe.

The age of 10 or 11 is the average time at which this type of patient seeks treatment for a "double ankle" that recently has become painful. On examination the ankle is in valgus, and the tuberosity of the navicular is quite prominent and cannot be hidden when the patient tries to elevate the arch. It is tender to palpation. A longitudinal arch support in a stiff-shanked shoe, contrast baths and foot exercises may give immediate relief. If they do not, removal of the accessory ossicle is indicated After resecting the ossicle, Kidner suggests fastening this free stump of the tibialis posticus tendon laterally under the navicular so that it will give support to the head of the talus. Usually the ossicle is within the tendon of the tibialis posticus at its insertion into the tuberosity of the navicular. On one or two occasions the author has found it to lie on the tendon in somewhat the same way that the patella lies under the patellar tendon.

SUMMARY

Usually, anomalies among the normally developed tarsal bones are due to coalescence between two or more of them through the medium of an ossicle. There are anatomic and clinical reports of fusions across all the tarsal joints. Of these, fusions across the subtalar and the calcaneonavicular joints are symptomatic.

In early life the bridge is fibrous or fibrocartilaginous, and the symptoms are in the nature of discomfort during activity. As these children become older, the bridge becomes bony, and the symptoms become more acute, developing the rigid static flat foot. The illustrative cases were found in the years between 1926 and 1935.

An ossicle may cause symptoms without bridging a joint, as in Kidner's "prehallux."

In the young children (discomfort stage), resection of the anomaly was practiced. In the older children, a triple arthrodesis was used.

If the symptomatic anomaly is not removed, the patient will continue to have a painful foot. As the age of 60 is approached, this condition becomes almost intolerable.

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Congenite Anormalitates del Ossos Tarsal

Summario in Interlingua

Le anormalitate que causa symptomas es del typo que resulta in fusion inter le ossos. Le fusion procede via le medio del tertie osso. Il existe reportos de fusiones inter omne le ossos tarsal. Le fusion trans le articulation subtalar e le fusion trans le articulation calcaneo-navicular deveni symptomatic.

In juvene pupos le symptomas es plus tosto un question de disconforto. In le secunde decennio del etate illos deveni invalidante, e le condition es alora cognoscite como pede plan spastico-rigide.

Un libere ossiculo accessori pote causar un typo de invaliditate que es exemplificate per le osso tibial externe.

Alleviamento pote esser effectuate in juvenissime patientes pediatric per abrasion del structuras anormal e in patientes approchante lor adolescentia per un triple arthrodesis.

5

Variation of the Digital Skeleton of the Foot*

P. VENNING†

The skeletal variations considered here are confined to a group or complex of characters affecting the digits of the foot. These have been selected from among the very numerous skeletal variations of the foot because they have certain characteristics that make them specially suitable for study. First, they occur with sufficient frequency among healthy people to make quantitative analysis possible in a sample of reasonable size. Second, they are phenotypically of a kind that has been of considerable phylogenetic importance. Thirdly, they appear to belong to a class of polygenic continuous variations that is probably of importance in the morphogenesis of the skeleton.

* The data and the results presented are based mostly on the author's own material, which consists of standard dorsiplantar radiographs of the feet of about 1,800 schoolchildren and about 500 adults of both sexes. The child sample consists of the school population from 5 to 14 years, inclusive, of a single urban population of Greater London at a particular date, and the adult sample consists of the staff and the students of a London college. Some of the data have been published previously (Venning, 1954 & 1956[28-30]).

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FIG 1 Right foot of a 19-year-old girl with 2 phalanges on each toe (Venning, P. Am J. Phys Anthropol N S 14:11)

VARIATION IN THE NUMBER OF DIGIT SEGMENTS

The number of phalanges in the toes may be either 3 or 2. In the 1st toe the number is almost always 2, though a 3-phalanged form of this toe has been reported from time to time. The postaxial toes, however, are much more variable. The first record of the 2-phalanged form of the 5th toe is due to Leonardo da Vinci (1492) Anatomists before him and after (e.g., Vesalius) described only the 3-phalanged form. For a long time the 2-phalanged form was thought to be due to fusion of previously separate middle and terminal phalanges during postnatal life, attributable supposedly to disuse of the joint or to injury Indeed, the terminal phalanx of the 2-phalanged form still is described frequently as "fused," although there is no evidence for this.

The frequency of the 2-phalanged form in the cartilaginous skeleton of fetuses as early as 12 weeks old (Trolle, 1948[26]) does not differ from the frequency among adults. In addition to the 5th toe, the 2nd, the 3rd and the 4th also have a 2-phalanged form, though much more rarely (Fig. 1). Toes

TABLE 1. THE FREQUENCIES OF TOES WITH TWO PHALANGES REPORTED BY DIFFERENT INVESTIGATORS

Investigator	Material	Method	Sex	No. of Feet	2nd Toe No.	2nd Toe %	3rd Toe No.	3rd Toe %	4th Toe No.	4th Toe %	5th Toe No.	5th Toe %
Pfitzner (1890)	European fetuses and children	Dissection	Both	91	0	—	0	—	0	—	37	40.7
Pfitzner (1896)	European adults	Dissection	Male	557	-	—	-	—	—	—	198	35.5
			Female	263	-	—	-	—	—	—	108	41.1
			Both	838	3	0.4	4	0.5	13	1.6	310	37.0
Hasselwander (1903)	European fetuses and children	Dissection and x-rays	Both	172	0	—	0	—	2	1.1	83	47.1
Hasselwander (1910)	European children and adults	Dissection and x-rays	Male	143	2	1.4	3	2.1	7	4.9	53	37.1
			Female	113	0	—	0	—	4	3.5	52	46.0
			Both	256	2	0.8	3	1.2	11	4.3	105	41.0
Adachi (1905)	Japanese adults	Dissection and x-rays	Both	97	-	—	-	—	3	3.0	80	80.4
Hasebe (1912)	Japanese adults	Dissection	Male	180	0	—	0	—	18	10.0	130	72.2
			Female	80	0	—	0	—	2	2.5	61	76.3
			Both	260	0	—	0	—	20	7.7	191	73.5
Trolle (1948)	European fetuses	Dissection	Both	370	0	—	1	0.3	2	0.6	137	36.0

In order to obtain uniformity, the sample sizes have been expressed in numbers of feet, since some workers have given this information only, without stating the number of individuals represented. Therefore, in their present form these data are not suitable for statistical comparisons.

(Venning, P.: Am. J. Phys. Anthropol. N.S. 11:4)

with only 2 phalanges, except the 1st, are always lateral in the foot to toes with 3 phalanges.

Table 1 gives the frequencies of the 2-phalanged forms found by different workers. These show a striking difference between European and Japanese frequencies, the 2-phalanged form of the 5th toe being much commoner among the latter. The 2-phalanged form of the 5th toe has been reported in the feet of Terra del Fuegan Indians, American Negroes, African Hottentots and Egyptians (Straus, 1927[25]) and in Australian aborigines (Abbie & Adey, 1953[1]). It may be safely concluded that variation in the number of phalanges has a world-wide distribution but that the frequencies of the different forms may vary considerably between population demes.

Table 2 gives the author's material analyzed in terms of the number of phalanges found in the different toes in right and left pairs of feet. The toes of children in whom fusion of ossification centers within phalanges has not taken place may be classified into 2- and 3-phalanged forms with a fair degree of certainty from the number and the relative size of the ossified centers present (Venning, 1956[29]). The frequencies show that the 2-phalanged forms occur significantly more often in females than in males. The preponderance of bilateral symmetry shows a very high correlation between the sides in respect to phalangeal number. Among asymmetric pairs of feet the 2-phalanged form occurs significantly more often on the left.

Occasionally, the terminal phalanx of a 2-phalanged 5th toe shows a fissure, or notch, that partially divides the bone into

TABLE 2. OCCURRENCE OF TWO AND THREE PHALANGES AMONG THE TOES OF THE FEET OF THE COMBINED SAMPLES OF CHILDREN AND ADULTS

Males					RIGHT FOOT					
	TOES			2nd	Three	Three	Three	Three	Two	
				3rd	Three	Three	Three	Two	Two	
				4th	Three	Three	Two	Two	Two	
	2nd	3rd	4th	5th	Three	Two	Two	Two	Two	TOTAL
LEFT FOOT	Three	Three	Three	Three	640	34	—	—	—	674
	Three	Three	Three	Two	43	387	1	—	—	431
	Three	Three	Two	Two	—	2	16	—	—	18
	Three	Two	Two	Two	—	—	1	6	—	7
	Two	Two	Two	Two	—	—	—	—	—	0
Total					683	423	18	6	0	1,130
Females					RIGHT FOOT					
	TOES			2nd	Three	Three	Three	Three	Two	
				3rd	Three	Three	Three	Two	Two	
				4th	Three	Three	Two	Two	Two	
	2nd	3rd	4th	5th	Three	Two	Two	Two	Two	TOTAL
LEFT FOOT	Three	Three	Three	Three	608	29	—	—	—	637
	Three	Three	Three	Two	60	457	2	—	—	519
	Three	Three	Two	Two	—	11	14	1	—	26
	Three	Two	Two	Two	—	—	1	2	—	3
	Two	Two	Two	Two	—	—	—	—	1	1
Total					668	497	17	3	1	1,186

(Venning, P.: Am J Phys Anthropol N.S 14:19)

proximal and distal parts. This condition has usually been interpreted as evidence of fusion between a middle and a terminal phalanx, though it could be regarded equally as evidence of incomplete segmentation. In the absence of any evidence of fusion between once-separate cartilaginous elements, this latter interpretation is preferred.

Among the schoolchildren in the author's material there were 296 families of sibs comprising 636 individuals. In the 391 sib pairs from this sample, there was a highly significant tendency for sibs to be alike with respect to the number of phalanges on 5th toes ($r = 0.28 \pm 0.05$, Venning, 1954[28]). This degree of correlation is too low for this character to be inherited as a single gene; however, it is consistent with polygenic determination.

Considering the foot as a whole, the following combinations of phalangeal number among the toes probably occur:

NUMBERS OF PHALANGES

	Toes					
	1st	2nd	3rd	4th	5th	
(a)	3	3	3	3	3	Very rare
(b)	2	3	3	3	3	about 55% Europeans; (25% Japanese)
(c)	2	3	3	3	2	about 40% Europeans; (75% Japanese)
(d)	2	3	3	2	2	about 2% Europeans
(e)	2	3	2	2	2	about 0.5% Europeans
(f)	2	2	2	2	2	< 0 1% Europeans

MIDDLE PHALANX REDUCTION

Phalangeal number is determined apparently by the presence or the absence of a separate middle phalanx. The terminal phalanx of the 2-phalanged form of 5th toe looks, both in size and in shape, as if it had been compounded from the middle and the terminal phalanges of the 3-phalanged form Evidence that, in a sense, this is what has occurred is provided by the different forms of middle phalanx found among 3-phalanged toes.

Middle phalanges may develop or fail to develop epiphyses. Between these extremes there is an intermediate form of pseudoepiphysis. Any one, or two, or all three of these forms may be represented among the toes of the foot. When more than one form is present, almost invariably a toe in which a middle phalanx possesses any epiphysis is medial to a toe with either of the other forms; similarly, a toe in which the middle phalanx lacks an epiphysis is lateral to a toe with either of the other forms. Toes with 2 phalanges are, of course, lateral to all these forms. Therefore, feet may be classified according to the combination of skeletal forms present among the toes, taking into consideration both the form of middle phalanx and the number of phalanges. Table 3 shows, for each sex, the frequencies of the different combinations in the feet of children. For sake of simplicity of presentation, a pseudoepiphysis has been counted as equivalent to an absence of epiphysis, and children with 2-phalanged toes in addition to the 1st and the 5th toes have been omitted (6 males and 9 females). Also omitted is a child who, on one foot, provided the only example of an exception to usual mediolateral positional order between toes with and without epiphyses of the middle phalanges. (The 2 adjacent toes involved in this case had syndactylous bony union between the terminal phalanges.) The children represented in this table are all the boys within the age group 7 to 10 years, inclusive, and all the girls within the age group 5 to 8, inclusive. At these ages classification according to the epiphysial forms of middle phalanx can be carried out with greatest certainty.

Analysis of these frequencies gives the following results:

Middle phalanges that lack epiphyses occur significantly more often among females than males. There is a highly significant tendency for bilateral symmetry of the feet; among asymmetric pairs of feet middle phalanges without epiphyses occur signifi-

TABLE 3. THE OCCURRENCE OF MORPHOLOGIC VARIATIONS OF THE MIDDLE PHALANGES IN CHILDREN OF EACH SEX

MALES 7-10 YEARS

Toes (2nd / 3rd / 4th / 5th)	Right Feet									Left Feet Totals
	+ + + +	+ + + −	+ + − −	+ − − −	− − − −	+ + + 2	+ + − 2	+ − − 2	− − − 2	
Left Feet: + + + +	—	—	—	—	—	—	—	—	—	—
+ + + −	1	51	2	—	—	—	—	1	—	55
+ + − −	—	7	68	4	—	—	4	—	—	83
+ − − −	—	—	8	26	2	—	—	2	—	38
− − − −	—	—	—	5	9	—	—	—	1	15
+ + + 2	—	—	1	—	—	8	—	—	—	9
+ + − 2	—	—	3	—	—	1	28	2	—	34
+ − − 2	—	—	1	6	—	—	4	46	1	58
− − − 2	—	—	—	—	1	—	—	3	19	23
Rt. Feet Totals	1	58	83	41	12	9	36	54	21	315

FEMALES 5-8 YEARS

Toes (2nd / 3rd / 4th / 5th)	Right Feet									Left Feet Totals
	+ + + +	+ + + −	+ + − −	+ − − −	− − − −	+ + + 2	+ + − 2	+ − − 2	− − − 2	
Left Feet: + + + +	—	1	—	—	—	—	—	—	—	1
+ + + −	—	31	3	—	—	1	—	—	—	35
+ + − −	—	2	65	4	—	—	—	—	—	71
+ − − −	—	—	7	48	—	—	2	3	—	60
− − − −	—	—	—	2	18	—	—	—	1	21
+ + + 2	—	3	—	—	—	2	1	—	—	6
+ + − 2	—	—	8	—	—	—	21	3	—	32
+ − − 2	—	—	1	3	—	1	2	45	1	53
− − − 2	—	—	1	1	2	—	—	3	41	48
Rt. Feet Totals	—	37	85	58	20	4	26	54	43	327

\+ = Middle phalanx with epiphysis.
— = Middle phalanx without epiphysis.
2 = Toe without middle phalanx.

cantly more often on left feet. There is a significant intrafoot correlation between the 2-phalanged form of 5th toe and middle phalanges lacking epiphyses.

Within feet, middle phalanges almost invariably get progressively shorter the more lateral the toe. On any particular toe, middle phalanx length is dependent, firstly, on its own epiphysial form (those lacking an epiphysis being on the average significantly shorter) and, secondly, on the skeletal form of middle phalanx present on each of the other toes in the foot (Venning, 1956[30]). Thus, the greater the number of toes in which the middle phalanx lacked an epiphysis, the shorter the middle phalanx of any particular toe. Similarly, middle phalanges are shorter in feet with 2-phalanged 5th toes than in feet with 3-phalanged 5th toes. Table 4 shows these relationships in the case of the 2nd toe

These results strongly suggest that all the different morphologic forms so far described form a related series characterized by different degrees of middle phalanx reduction, the first step being the transition from true epiphysis to pseudoepiphysis, the next step being the complete absence of an epiphysis, and the final step being the absence of an independent middle phalanx in the toe.

Though the morphologic steps in this series are discrete qualitative differences, the correlated variation of middle phalanx length suggests that the underlying middle phalanx reduction is a continuous variable. Interpreted in this way the frequencies of the different morphologic forms among the toes, and their relative mediolateral position, may be regarded as the expression of quantitative variation in the mediolateral distribution within the foot of some continuous morphogenetic variable promoting middle phalanx development Figure 1 depicts these conditions diagrammatically, showing a double gradient of the supposed morphogenetic factor, with its maximum value at the 2nd toe, and decreasing abruptly medially and more gradually laterally.

TABLE 4. MEAN LENGTHS IN MM. (CORRECTED TO A STANDARD AGE OF 7 YEARS 10 MONTHS) OF THE MIDDLE PHALANX OF THE 2ND TOE ON LEFT FEET OF GIRLS 4 TO 10 YEARS IN SAMPLES WITH DIFFERENT COMBINATIONS OF MIDDLE PHALANX VARIATIONS. LEVEL OF SIGNIFICANCE, P = 0.05. THE FEET IN ALL THESE SAMPLES WERE ALIKE IN RESPECT TO THE FORM OF EPIPHYSES IN THE PROXIMAL PHALANGES (I.E., NONCONIC).

	Middle Phalanx Variation on Toes				No. of Feet	Length (mm.) Middle Phalanx of 2nd Toe		Significance (P) of Differences in Means Related to			
	2nd	3rd	4th	5th		Mean	S.E.	± Epiphysis		No. of Phalanges	
a	+	+	+	—	48	10.66	0.024	a-b	<0.001	a-c	not sig.
b	+	+	—	—	88	10.00	0.012	b-c	<0.020	b-f	not sig.
c	+	—	—	—	65	9.56	0.018	c-d	<0.001	c-g	not sig.
d	—	—	—	—	18	8.45	0.062	a-d	<0.001	d-h	<0.010
e	+	+	+	2	6	10.07	0.750	e-f	not sig.		
f	+	+	—	2	42	9.92	0.028	f-g	<0.010		
g	+	—	—	2	59	9.25	0.019	g-h	<0.001		
h	—	—	—	2	49	7.52	0.023	e-h	<0.010		
	Sum of differences in means								<0.001		<0.050

\+ = Middle phalanx with epiphysis
— = Middle phalanx without epiphysis.
2 = Toe without middle phalanx.

If this interpretation is true, each of the morphologic forms described falls into the class of quasi-continuous characters described by Grüneberg (1951 & 1952[7,8]) in the mouse skeleton. Grüneberg suggested that some skeletal differences—for example, the occasional absence of the 3rd molar tooth in a strain of mice—were due to a continuous variable—in this case the amount of precursor tissue available for tooth formation—being less than a threshold value.

The relation between middle phalanx length and the morphologic differences being considered here suggests that a continuous variable underlying these differences might be variation of middle phalanx, or presumptive middle phalanx, length. It is reasonable to suppose that a certain minimum of cartilaginous tissue is required at some stage of differentiation for successful epiphysial development. Fell and Canti (1934),[6] in experiments on the formation of chick embryo knee joints in vitro, found that one of the requirements for successful segmentation at this joint was the presence of a sufficient length of skeletal tissue on either side of the presumptive joint region. Joint formation occurs at the place of meeting of two expanding centers of chondrification (Murray, 1936[16]). In the digits the center of chondrification for each presumptive segment and the joints between the segments appear in proximodistal succession (Senior, 1929[24]). Variation in the relative positions of the centers of chondrification along the digit blastema, or in the relative times of their appearance, or rates of expansion, might create conditions in which the length of the presumptive middle phalanx was insufficient for segmentation to occur between the presumptive middle and terminal phalanges. Such a situation would give rise to a 2-phalanged toe.

The almost invariable occurrence of only

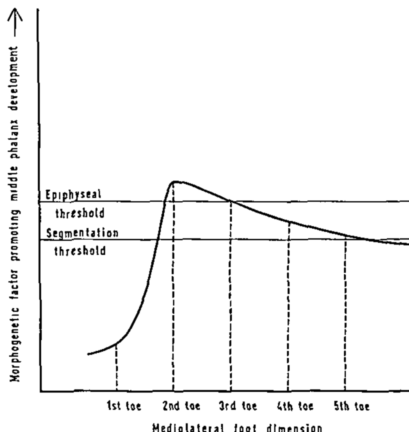


FIG. 2. Hypothetic mediolateral distribution of a morphogenetic factor promoting middle phalanx development. As the quantity of the factor falls below successive thresholds it is supposed that, first, the middle phalanx lacks an epiphysis, and, finally, the toe lacks a middle phalanx.

2 phalanges in the 1st toe is not, as might appear, an obstacle to this hypothesis, since it is probable that at the time of digit segmentation this ray is the shortest in the foot (Schultz, 1924;[23] Straus, 1927[25]).

It was suggested above that variation of the processes of initial proximodistal chondrification of the digital blastema might bring about variation of middle phalanx lengths In considering the more fundamental morphogenetic factors that might in turn affect these processes, one is perhaps entering a purely speculative field. Nevertheless, it is worth remarking that the reciprocal influence of ectoderm and skeletal mesoderm of the limb bud, and particularly the influence of the apical ectodermal ridge, is one of the fundamental morphogenetic determinants of proximodistal differentiation and growth of the limb skeleton of the chick embryo (Saunders, 1948,[22] Zwilling, 1955 & 1956[33,34]) and of Xenopus tadpoles (Tschumi, 1957[27]) There is some evidence that these relationships may also apply in man (Zaaijer, 1953[32]). The prepostaxial alignment of the apical ectoderm ridge of the limb bud might well be capable of producing the sort of mediolateral quantitative distribution illustrated in Figure 1.

Wood Jones (1944)[31] and others have suggested that the reduction of middle phalanges in the more lateral toes is an evolutionary change supposedly advantageous from the point of view of stability. It is certainly true that changes in the number of phalanges has been a repetitive theme in vertebrate evolution in the direction of both reduction and increase. *Ungulates* provide obvious examples of the one and *Cetacea* of the other. Variation of phalangeal number, upon which selection could operate, must have occurred frequently within breeding demes of many different species during evolutionary history However, the occurrence in man of variation of this character is not in itself evidence of any evolutionary trend unless selective pressure can be demonstrated or there is at least clear evidence

that one or other form is advantageous. In this case there appears to be no such evidence.

VARIATION OF EPIPHYSES OF THE PROXIMAL PHALANGES

The relation between the skeletal variations so far described and middle phalanx length raises the question whether or not the length of other bones of the foot are also related to these variations. This question cannot be answered without taking into account yet another skeletal variation of digits. This variation consists of variation in the shape of the epiphyses of the proximal phalanges. Figure 3 illustrates extremes of this apparently continuous variation. It will be seen that one tail of this distribution is characterized by a pronounced distal projection of the ossified epiphysis into an accommodating crater of the diaphysis. Lateral radiographs confirm that this projection is more or less axial to the shaft of the phalanx.

Brailsford (1944)[3] reported extreme examples of these conic epiphyses in the phalanges of the hands or the feet of children affected by a dyostosis, which is thought to arise from abnormal differentiation of the mesodermal precursor of both cartilage and membrane bone. Of course, the present examples were observed in a sample of apparently healthy children. At a certain stage of epiphysial development in some reptiles (Haines, 1938 & 1942[9,10]) and in birds (Fell, 1925[7]), a long cone or peg of cartilage projects from the epiphysis into the diaphysis. This peg is formed, in the fowl at least, by marrow erosion of cartilage at the periphery of the shaft proceeding toward the articular end of the shaft in advance of similar erosion of the center. At a later stage the peg also is eroded. These pegs appear to differ from the cones under discussion here in that the growth zone of epiphysial cartilage is not part of the projection.

Criteria were established to fix an arbitrary division of the continuous shape distribution, so that the epiphysis of each proximal phalanx might be classified as conic or not conic according to the degree of distal projection of the axial part. Table 5 shows the frequency distribution by age in each sex of the left feet of children classified according to whether one or more of these epiphyses

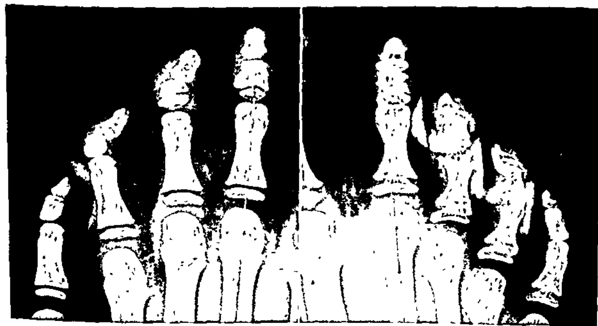


FIG 3. Examples, in two 8-year-old girls, of the extremes of shape variation of epiphyses of the proximal phalanges.

was conic or all were nonconic. Conic epiphyses occur much more frequently in females than in males. In both sexes, within the age range at which none of these epiphyses is fused, the frequency of conic epiphyses does not vary consistently with respect to age. At older ages, as the proportion of children with fusion increases, so the frequency of conic epiphyses among the remaining children without fusion tends to decrease. Thus it appears that conic epiphyses tend to fuse earlier than nonconic epiphyses. Inspection of the radiographs suggests that in conic epiphyses this fusion starts axially at the apex of the cone.

The distribution of conic epiphyses among the toes is the same in each sex and shows a significant tendency to bilateral symmetry with no differences between right and left in the frequencies of asymmetric conditions.

TABLE 5. FREQUENCIES, AT DIFFERENT AGES, OF CONIC EPIPHYSES OF THE PROXIMAL PHALANGES IN CHILDREN WITH NONE OF THE EPIPHYSES OF THESE PHALANGES FUSED

Age at Last Birth-day	Total in Samples	% Children With Fusion of One or More Epiphyses	A. Children With No Fusion	B. Children With Conic Epiphyses	Col B As % of Col. A
		Males			
4	24	Nil	24	Nil	Nil
5	88	Nil	88	7	7.9
6	82	Nil	82	3	3.7
7	88	Nil	88	8	9 1
8	61	Nil	61	5	8.2
9	72	Nil	72	8	11 1
10	98	Nil	98	8	8.2
11	91	Nil	91	10	11.0
12	93	Nil	93	6	6.5
13	109	5 5	103	6	5 8
14	92	20.7	73	2	2.7
15	14	35.7	9	Nil	Nil
Totals (4-12 yrs.)			697	55	7.9
(13-15 yrs)			185	8	4 3
		Females			
4	24	Nil	24	4	16 7
5	80	Nil	80	19	24 8
6	93	Nil	93	31	33.3
7	89	Nil	89	19	21 3
8	73	Nil	73	22	30 1
9	60	Nil	60	17	28 3
10	87	Nil	87	18	20 7
11	85	4 7	81	11	13 6
12	122	27.0	89	16	18 0
13	113	49 6	57	5	8 9
14	83	80 7	16	Nil	Nil
15	12	75 0	3	Nil	Nil
Totals (4-10 yrs)			506	130	25 7
(11-15 yrs)			246	32	13 0

TABLE 6. DISTRIBUTION OF CONIC EPIPHYSES OF PROXIMAL PHALANGES AMONG THE TOES OF RIGHT AND LEFT FEET OF GIRLS OF 4 TO 10 YEARS, INCLUSIVE

	Toes With Conic Epiphyses of the Proximal Phalanges	Right Feet							Left Feet	
		None	— 3rd — —	2nd 3rd — —	— 3rd 4th —	2nd 3rd 4th —	— 3rd 4th 5th	2nd 3rd 4th 5th	Totals	%
Left Feet	None	376	3	—	2	—	—	—	381	75.3
	— 3rd — —	7	32	1	6	1	—	—	47	9.3
	2nd 3rd — —	—	4	5	—	1	—	—	10	2.0
	— 3rd 4th —	2	6	—	20	5	—	—	33	6.5
	2nd 3rd 4th —	—	1	1	4	25	—	2	33	6.5
	— 3rd 4th 5th	—	—	—	—	—	—	1	1	0.2
	2nd 3rd 4th 5th	—	—	—	—	—	—	1	1	0.2
Right Feet	Totals	385	46	7	32	32	—	4	506	
	%	76.1	9.1	1.4	6.3	6.3	Nil	0.8		

Table 6 gives the distribution of conic and nonconic epiphyses among the toes of girls. When a conic epiphysis is present in the foot, the third toe is always affected; if more than one toe is affected, then successively adjacent toes medially or laterally, or both, are affected. Toes lateral to the 3rd toe are affected more frequently than toes medial to the 3rd. An epiphysial configuration very similar to a conic epiphysis was seen occasionally on the 1st toe, but this toe has not been included in the analysis because the morphologic differences were sufficient to make a comparable classification impossible. Among the other toes the order of frequency of conic epiphyses, 3>4>2>5, corresponds to the usual sequence of onset of epiphysial ossification (Pyle & Sontag, 1943[21]; Harding, 1952[11]).

Feet may be classified with respect to both conic and nonconic epiphyses of the proximal phalanges and to the variations of the middle phalanges. The frequency distributions in Table 7 show that conic epiphyses

TABLE 7. DISTRIBUTION OF THE DIFFERENT COMBINATIONS OF MORPHOLOGIC VARIANTS OF THE MIDDLE AND THE PROXIMAL PHALANGES OF LEFT FEET OF GIRLS AGED 4 TO 10 YEARS

	Middle Phalanges With Epiphyses (+), Without Epiphyses (—), and Absent (2)								
2nd toe	+	+	+	—	+	+	+	—	
3rd toe	+	+	—	—	+	+	—	—	
4th toe	+	—	—	—	+	—	—	—	
5th toe	—	—	—	—	2	2	2	2	Totals
Feet without conic epiphyses of proximal phalanges	48	89	66	18	6	43	60	50	380
Feet with conic epiphyses of proximal phalanges	6	14	19	19	1	5	20	40	124
Totals	54	103	85	37	7	48	80	90	504

series. It is reasonable to assume that the variable connecting this series is some property of the epiphysial plate cartilage that determines the length of time during which it is immune to the chondrolytic action of marrow invasion and subsequent endochondral ossification. Thus, when no epiphysial apparatus is developed, it may be supposed that the spread of osteogenic tissue within the shaft proceeds uninterruptedly to the articular end of the bone. Parsons (1905)[17] describes long bone ossification in the pigeon in which the spread of ossification along the shaft is halted temporarily at a position corresponding to a presumptive epiphysial plate but then proceeds up to the articular end. In the case of pseudoepiphysis development, the spread of endochondral ossification is halted at first at the level of the presumptive epiphysial plate and then breaks into the articular end through an approximately axial corridor surrounded by a peripheral ring of apparently competent epiphysial plate cartilage that survives for a more or less prolonged period (Posener, Walker & Weddell, 1939[20]). In the case of complete epiphysial development, the epiphysial plate constitutes an intact and more permanent barrier to the spread of ossification from the diaphyses, but in the more conic examples the breakdown of this barrier occurs earlier and commences axially.

Thus, the morphogenetic factor underlying these correlated forms of epiphysis may be supposed to be concerned with promoting epiphysial plate formation. Judging by the

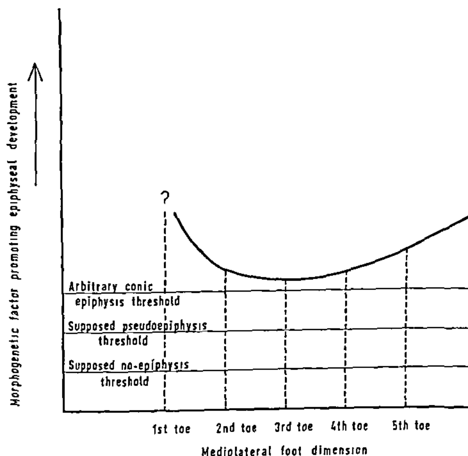


FIG 4 Hypothetic mediolateral distribution of a morphogenetic factor promoting epiphysial development in the phalanges. As the quantity of the factor falls below successive thresholds it is supposed that epiphyses tend to be conic, then "pseudo" and, finally, absent.

frequencies with which conic epiphyses occur among the toes, the quantitative distribution of this factor within the foot appears to be at least at the position of the 3rd toe and to increase on either side, more abruptly medially than laterally (Fig. 2). This distribution is the opposite of that shown in Figure 1 for the supposed morphogenetic factor promoting middle phalanx development.

The nature of the morphogenetic factors determining epiphysial differentiation is unknown. In the long bones of vertebrates, the most universal, and consequently perhaps the most primitive, characteristic of epiphysial differentiation is a layer of flattened proliferating cartilage cells separating the undifferentiated cartilage at the articular end of the bone from the shaft. Some degree of differentiation of such a layer has been reported in all vertebrates examined, including fish (Haines, 1938[9]). Whether or not the cartilage of the articular end ossifies, and whether it ossifies from the diaphysis or from an independent center, and whether such a center eventually undergoes osseous union with the diaphysis are variable characteristics. The development of separate epiphysial centers of ossification seems to be a secondary specialization mainly confined to mammals. Lütken (1947)[15] reports that the presumptive epiphysial and diaphysial parts of long bones are recognizable in the cartilaginous models in man and other vertebrates by differences of surface structure, the diaphysial surface being more definite and abrupt, while the epiphysial surface grades off into the surrounding nonskeletal tissue. Such a difference might be correlated with differences in diffusion properties of the two parts that could influence cartilage differentiation.

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Variationes in le Skeleto Digital del Pede

Summario in Interlingua

Es analysate duo independente gruppos de variationes morphologic del digitos pedal que es communmente incontrate in subjectos normal. Le prime gruppo consiste de un mutualmente correlationate serie de differentias que affice le phalanges intermediari, i.e. phalanges con epiphyses, phalanges con pseudo-epiphyses, phalanges sin epiphyses, e absentia de phalanges intermediari. Le secunde gruppo consiste de variationes del proximal, correlationate con le variationes conformation del epiphyse in le phalanges proximal, correlationate con le variationes del epiphyses in le phalanges intermediari sed non con lor absentia.

Le duo gruppos differe in lor distribution inter le digitos. Ambes exhibi differentias de frequentia inter le sexos. Le prime gruppo es strictemente correlationate con le longor del phalange intermediari. Le secunde gruppo es correlationate con le longor de omne o del majoritate del ossos del pede. Es discutite le factores ques determina possibilemente iste variationes. Es concludite que le factores in ambe casos es probabilemente variabiles continue. Un, concernite con le disveloppamento del phalange intermediari, es probabilemente relationate con le un o le altere proprietate del differentiation de cartilagine, occurente ante le segmentation del digito e determinante le longor del phalange intermediari. Le altere pare esser concernite con le differentiation del placa epiphysee.

6

The Transverse Tarsal Joint and Its Control

HERBERT ELFTMAN, PH.D.*

The foot is a pivotal component of the human locomotor structure since it controls the vital contact of our bodies with the ground. Proper management of the foot provides us with our final opportunity to compensate for deficiencies in control of other parts of the body. Conversely, when the foot is negligent in the performance of its function, additional loads, which may prove to be excessive, are transferred to other components of the mechanism.

Since the foot is important to us because of its function, its scientific study involves the correlation of physiologic measurement with anatomic structural analysis. Brief reviews of the contributions of earlier workers, combined with an account of their researches, will be found in the following:

1. For the distribution of pressure in the human foot, Elftman (1934)[2]
2. For moments of force of muscles acting on the foot, Elftman (1939)[3]
3. For the functional interpretation of the structure of the ankle joints, Manter (1941).[10] Many of the later studies have been stimulated by the intensive program of research on artificial limbs organized by the National Research Council, some of the results of which have appeared in *Human Limbs and Their Substitutes*, edited by Klopsteg and Wilson (1954).[9]

At first glance it appears paradoxical that the foot should play an important part in the locomotor problems of the amputee. It is a geometric truism that the foot must be lost more often than any other part of the body in a lower extremity amputation. The design of the artificial foot that is substituted can benefit from a knowledge of the normal, although it can hardly be expected to equal it in functional capacity. So it is inevitable that the natural foot remaining in the unilateral amputee works under a double burden that heightens the importance of its structural characteristics.

Communication between the foot and the rest of the locomotor mechanism is channeled through the ankle, conferring on it exceptional responsibility for the proper management of locomotor performance. Although the more distal portions of the foot are also of great importance, they cannot challenge the supremacy of the ankle in guiding movement. Consequently, we shall focus our attention on significant features of the ankle joint and the mechanisms that cooperate in their control.

TALOCRURAL AND SUBTALAR JOINTS

The articulation that frequently is called "the" ankle joint in American usage and the upper ankle joint in Europe we shall refer to as the talocrural articulation, with movements recorded as dorsiflexion and plantar flexion. Our only concern with this joint will be its influence on the subtalar joint. Since the talus receives no muscular insertion, control of the talocrural and the subtalar joints is exercised by a common set of muscles.

The subtalar joint—the lower ankle joint

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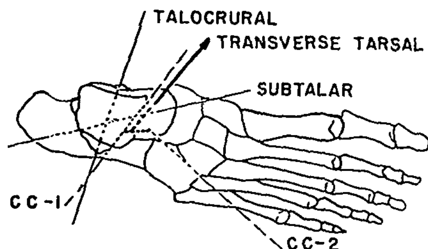


FIG. 1. The major joint systems of the ankle. The instantaneous position of the axis of the transverse tarsal joint is represented by an arrow that originates on the short line that is perpendicular to both CC-1 and CC-2, the two axes of the saddle-shaped calcaneocuboid joint. The talocrural and the subtalar axes have their usual positions. The talonavicular axes are not shown.

in European usage—permits movement between the talus and the calcaneus. Although the area of contact of the body of the talus with the posterior articular facet of the calcaneus lies in a synovial cavity separate from that which houses the contact areas of the head of the talus and the calcaneal sustentaculum, they are all integral parts of the subtalar joint.

The mechanical characteristics of the subtalar joint have received the attention of many competent investigators, whose work has been climaxed by the more recent investigation of Manter (1941).[10] The range of movement in this joint has been measured for feet of various structure by Close and Inman (1953).[1] The relations of the subtalar joint to the talocrural were summarized by Elftman (1954).[9] We shall use the terms *inversion* and *eversion* to describe rotation about the axis of this joint.

TRANSVERSE TARSAL JOINT

The third member of the family of ankle joints is the transverse tarsal joint, known also by the shorter names of midtarsal and Chopart. It has yielded its secrets more reluctantly than have the talocrural and the subtalar joints, therefore, it invites our attention now.

The transverse tarsal joint lies at the very heart of many of the problems of the foot, forming, as it does, a clear-cut division between the calcaneus and the talus behind and the entire remainder of the foot in front. It is in this joint that normal heightening and lowering of the arch of the foot takes place. The terminology that we shall adopt is that of calling rotation in the transverse tarsal joint in the direction that raises the arch by the term *supination*, rotation in the direction of a lower arch being pronation. These terms are used in various special ways by various people, but the general sense is within the limits of our definition.

Although the cuboid and the navicular are not completely rigidly attached to each other, any relative movement between them is so minor that we are entitled to consider these two bones as moving together as a first approximation. This allows us to look at the ankle complex as a fairly simple kinematic chain containing only three elements: calcaneus, talus and cuboidnavicular.

It is convenient to use the calcaneus as the reference ("stationary") element. There are two ways in which we can describe the movement of the cuboidnavicular with respect to the calcaneus. The most direct way is to record the movement in the calcaneocuboid joint. The other method is more circuitous, since it involves combining the movement of the talus in the subtalar joint with that of the cuboidnavicular in the talonavicular joint. These two methods must give identical results since they describe the same movement. In other words, the movement that occurs is the one congenial to

both joint systems in the positions that they occupy at the moment.

The structure of the calcaneocuboid joint intrigued Adolph Fick[9] to the extent that, in 1854, he made it the subject of a paper on saddle-shaped joints. A modern interpretation of this characteristic is shown in Figure 2. The degree of curvature of both aspects of the saddle vary greatly. However, the eye of the connoisseur never has difficulty in recognizing both axes.

Of the two axes of the calcaneocuboid joint, the one that is governed by the convex surface of the calcaneus must lie within that bone; it is designated CC-1 in our figures. If it were projected upward, it would pass through the head of the talus. The other axis, CC-2, lies in the cuboid bone and is directed at right angles to the first axis. They do not lie in the same plane. The shortest perpendicular distance between these axes is shown by a line in Figures 1 and 2, and by a black disk in Figure 3.

The importance of this line's representing the shortest perpendicular distance lies in the fact that the resultant movement in the transverse tarsal joint due to combined movement about the two calcaneocuboid axes *must always* be about an axis that passes through this line. Such a resultant is shown in Figure 1.

Having described the constraints that the calcaneocuboid joint axes put on the position of the resultant transverse tarsal axis, we can transfer our attention to the subtalar and the talonavicular combination, which must also be able to produce the same movement. In Figure 2, the axis of the subtalar joint is shown. The talonavicular joint, being condyloid, has two axes passing through the talus, the larger radius of curvature belonging to TN-1, the smaller to TN-2. The detailed measurement of the characteristics of these joints, including translation along the subtalar axis, presents a formidable problem. It would seem very unlikely that any normal combination of characteristics would allow the transverse tarsal axis to

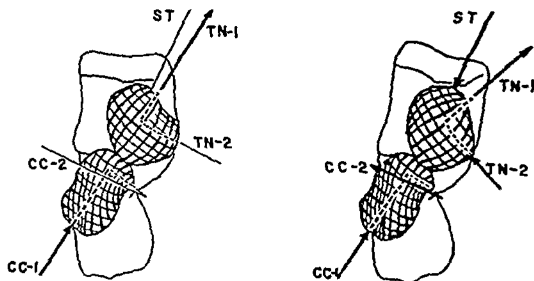


FIG 2. The transverse tarsal joint is shown in a pronated position at the left and a supinated one at the right. In the fully pronated position, which only a *normal flat foot* can achieve, the axis of the convex curvature of the calcaneus —CC-1—coincides with the axis of the major curvature of the talus—TN-1—allowing *free movement without* involving other axes. In the supinated position the resultant of both calcaneocuboid axes must be identical with the resultant of the two talonavicular axes and the subtalar. The general direction taken by this resultant is shown in Figure 1. The contour lines on the articular surfaces aid in appreciating the rotations involved.

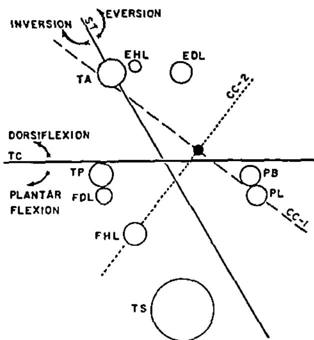


FIG. 3. Muscular control of the ankle joints. The axes are shown for the talocrural (TC), the subtalar (ST) and the proximal and the distal calcaneocuboid joints (CC-1, CC-2). The axis of the transverse tarsal joint varies with the position of the ankle, but it must always pass through the black disk of the diagram, since it represents the perpendicular line connecting the 2 calcaneocuboid axes The muscles are represented by circles that have an area proportional to the physiologic cross section of the muscle The positions of the circles reflect actual measurements of their lever arms with respect to the joint axes. In a general way, this diagram corresponds to an anatomic section cut obliquely through the ankle so as to be parallel to the joint axes shown.

The muscles should be recognizable from their position and the initials that identify them. Proceeding in a clockwise direction, they are TA, tibialis anterior; EHL, extensor hallucis longus, EDL, extensor digitorum longus, PB, peroneus brevis; PL, peroneus longus; TS, triceps surae, FHL, flexor hallucis longus; FDL, flexor digitorum longus; TP, tibialis posterior

escape the confines of the head of the talus. The position shown in Figure 1 may be regarded as typical.

The position of extreme pronation shown at the left in Figure 2 is of interest because the major axis of the talonavicular joint, TN-1, is directly in line with the axis of the calcaneocuboid joint, CC-1, which passes through the calcaneus. This allows the forepart of the foot to move freely with respect to the hindpart without movement of the talus with respect to the calcaneus. The possibility of doing this is one of the privileges of the flat foot, unattainable by the average foot with a sustained high arch.

In the supinated position shown to the right in Figure 2, each of the joint axes shown must contribute a measure of movement such that the resultant will be congenial to the entire system. In passing from the pronated to the supinated position there is a continuous change in the positions of the significant joint elements and, consequently, of the instantaneous transverse tarsal axis. The mapping of these instantaneous positions and the translational components associated with them would be well worth doing on a series of representative feet.

CONTROL OF THE TRANSVERSE TARSAL JOINT

The behavior of the transverse tarsal joint resembles that of all other joints in that the normal constraints of its movements depend on the presence of sufficient compression of the joint surfaces so that the movements will be guided by the shapes of these surfaces. It is for this reason that an evaluation of the biomechanical characteristics of any joint can be obtained only if it is under slight compression For the foot this can be accomplished by having the subject stand lightly on the foot while noting the movements that can be performed by the upper segments under these conditions.

With the weight of the body on the foot it is easy to demonstrate that movements of the talus can transmit sufficient force to the transverse tarsal joint to raise the arch without direct muscular intervention. The easiest way to demonstrate this is to stand erect on one leg and then cause it to rotate by pushing against the floor with the opposite foot.

Rotation of the weight-bearing leg with respect to its foot can be accomplished only by rotation in the subtalar joint, and this drives the transverse tarsal joint into supination.

Direct muscular control of the ankle joints is an extremely important factor in movement as well as in standing. Figure 3 has been constructed so as to furnish an approximate guide to the capabilities of the major long muscles. The lever arms of the muscles were determined by direct measurement. Physiologic cross sections for the muscles were obtained from Fick (1911).[7] While looking over this figure one is impressed by the extent to which the muscles are arranged to act as antagonists to gravity.

DISCUSSION

It is interesting to note that little evidence remains for the position of the transverse tarsal joint postulated by Fick (1911).[7] A transverse position for the resultant axis was first suggested by Elftman and Manter (1941),[10] and the results of the present investigation indicate the sagacity of that conclusion.

One of the difficulties inherent in understanding the foot is the fact that the joint systems are studied most easily with the use of some internal element, such as the calcaneus, as a steady reference point while the important work of the foot is really done with the ground as the substrate. It is to be hoped that the excellent methods of Hicks (1953)[8] will continue to pave the way toward more certain conclusions.

CONCLUSION

The transverse tarsal joint can be studied best by considering its calcaneocuboid portion first. The two axes of this saddle-shaped joint are well defined, and we know that the resultant movement when we use both axes at once must involve an instantaneous axis that passes through the perpendicular line connecting the two calcaneocuboid axes; in man, this passes just below the sustentaculum. The direction of this axis must also pass through the head of the talus, since it must also represent the combined rotations of the subtalar and the talonavicular joints. With this knowledge concerning the range of possible positions of the instantaneous axis of the transverse tarsal joint, it is possible to understand some of the gravitational and muscular factors that are important for its control.

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Le Articulation Tarsal Transverse e Su Rolo Functional

Summario in Interlingua

Le articulation tarsal transverse occupa un loco strategic in le pede que permitte a illo dominar le relationes inter le parte posterior del pede, i.e. le talo e le calcaneo, e le remanente elementos del pede anterior. Un movimento in iste articulation que resulta in un plus alte arco constitue supination; un movimento contrari resulta in pronation. Le clave al comprension del articulation tarsal transverse es recognoscer que su axe instantanee debe esser determinate per le movimentos que occurre in le selliforme articulation calcaneocuboide e debe etiam esser in harmonia con le combination de characteristicas possedite per le articulationes subtalar e talonavicular. Le axe del movimento tarsal transverse curre sub conditiones medie in direction oblique a transverso le calcaneo e le capide navicular. Illo non curre in direction longitudinal. Le relationes inter le musculos del cavilia e le articulationes del cavilia pote esser summarisate diagrammaticamente per representar le relationes de lor bracios levatori con le axes subtalar, talocrural, e calcaneocuboide.

7

The Mechanics of the Foot Based on the Concept of the Skeleton As a Statically Indetermined Space Framework

SIGFRID ZITZLSPERGER, M.D.*

INTRODUCTION

The functional interpretation of the skeleton of the foot as an arch is an old concept. A review of its history thereon was presented by E. Abramson (1927).[1] The old basic arch concept of the foot still is accepted today, as recorded in the major textbooks of the anatomic and the orthopaedic sciences. No progressive development or refinement of this arch concept has been made during the last 50 years; instead, many different modes of description and interpretation have been formulated. No agreement can be found even on such essential problems as the presence or the absence of a transverse arch, the bones that make up the individual arches, the specific bone that can be considered as the keystone of the arch This lack of agreement indicates plainly the complexity of the problem of a functional interpretation of the foot skeleton. This complexity has been expressed by many investigators. R Fick (1911)[3] concludes, "The structure of the foot is such which does not have any counterpart in the technique." F. Wood Jones (1944) says, "Most certainly the longitudinal arch in its structure and principle is quite unlike any arch ever designed by architects or engineers." J. H. Hicks (1955)[4] states, "The foot is one of the most complex and highly coordinated mechanisms in existence."

In view of its complexity, it is quite obvious that a serious challenge to the arch concept of the foot never can arise through approaches that neglect minute yet fundamental anatomic features, as has been the case in the past with the tripod approach or the treatment of the whole foot as a solid body (P. Lewin,[6] C. O. Bechtol,[2] R. L. Jones[5]). Serious modifications of the arch concept were advanced by J. T. Manter (1946),[7] who recognized the importance of the intertarsal joints for the mechanics of the foot. Manter measured the pressures that occur in the different intertarsal joints. He concluded that the forces of the body weight did not simply spread down following several pathways but that there was an arrangement of internal stresses that opposed the action of external forces. Manter observed "transverse compression" between the lateral and the medial parts of the foot and concluded that there was no basis for dividing the foot functionally into lateral and medial segments. In Manter's opinion, the whole foot structure is involved in weight-bearing, the raised portion of the longitudinal arch being of major import. Manter's experimental approach gave reliable evidence for his modifying ideas but

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did not produce a new functional concept of the foot structure.

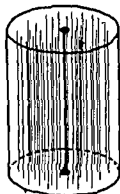
Another approach to test the validity of the classic arch concept is by assaying methods that apply rigorously the laws and the rules of analytic mechanics to the foot skeleton. In view of the significance of the intertarsal joints (emphasized by Manter), these, along with the individual configurations of the bones, will be considered in the present analysis of the problem.

THEORY OF METHOD EMPLOYED

The rules and the laws of analytic mechanics can be applied most easily when the foot skeleton is in the static condition; i.e., when at rest. In this condition there is an equilibrium between the external and the internal forces. The external forces are those which act from the outside upon the foot skeleton. Normally, external forces are the body weight that acts at the talocrural joint and the force reactions that act at the metatarsal heads and at the tuber calcanei. Internal forces are the forces that act within the skeleton. They resist the tendency of the external forces to push the members of the skeleton apart and act as forces of contact between the jointed members of the skeleton. Internal forces are also called stresses.

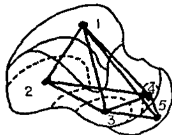
Mechanical forces, whether external or internal, are invisible and traditionally have been regarded as straight lines that can either push or pull in reference to one direction. Forces in structures are distributed in infinite numbers. In order to be able to manipulate these distributed forces, it is customary, in analytic mechanics, to reduce these to one concentrated force that is thought of as having all the properties of its parent forces. The points of application of such a concentrated force or stress are the centroids of the area of contact of the body with another one (Fig. 1A). When this simplified principle of concentrated stresses is applied to a bone, its articulating surfaces are the areas of contact, and the concentrated stresses extend between the centroids of its articulating surfaces (Fig. 1B). This principle is applied to all bones of the foot skeleton. The result of this application is a

A CYLINDER



B TALUS





DISTRIBUTED STRESS CONCENTRATED STRESS • CENTROID

FIG 1. The concept of distributed stresses and their replacement by a concentrated stress. The infinite numbers of distributed stresses are reduced for reasons of clarity to stresses that are recognizable individually.

three-dimensional simplified stress structure that displays the concentrated stresses possible between the centroids of all articulating surfaces. The representation of these concentrated stresses by brass rods, as done in this investigation, permits the construction of a model of the simplified stress structure of the foot skeleton.

The execution of such a model depends on the knowledge of the spatial positions of the centroids of the articulating surfaces. These positions can be obtained by observation of the following relationships. The position of the centroid of an articulating surface in reference to a point on its surface is a function of the shape of the surface. The position of the reference point depends on the spatial orientation of the bone, and its position depends on the bone's relative place in the foot skeleton. Another physical principle must be observed for the establishment of the individual concentrated stresses. This principle states that a mechanical force requires a substrate to act upon. The presence of bone or cartilage along the course of a concentrated stress between two centroids is necessary for its establishment, and the absence of these substrates will prohibit the existence of a concentrated stress. The curvatures and the sulci of the individual bones, as well as the gaps and the recesses between neighboring bones (strikingly numerous in the foot skeleton), gain a new functional significance, for these features determine the existence or the lack of stresses. Finally, as another simplification, the male and the female articulating surfaces of the joints are being considered as having a congruent shape, only one centroid per joint being determined

TEST OF METHOD

The bones of a left foot were glued together in such fashion that each joint was adjusted to its median position. Then three check points were marked on each bone, and their x, y, z co-ordinates were measured with an apparatus built specially for the purpose. After the foot skeleton had been disassembled, each bone was mounted individually in its relative position within the foot by adjusting the check points of the bones to their previously measured co-ordinates. The next step was to measure the co-ordinates, using again the same co-ordinate system, of new reference points marked on every articulating surface. Then, two photographic projections of every articulating surface of each bone were made, each bone being in its relative position within the foot. For the selection of the two planes of projection it was a requisite procedure to have each co-ordinate axis represented; i.e., xy and xz, or yz and yx, or xz and yz. These photographic projections recorded simultaneously the directions of the axis of these planes and a scale. The enlargements of these projections of the articulating surfaces were used for the determination of the co-ordinates of their centroids by the following graphic method, adapted from Seely and Ensign[9] and shown in Figure 2.

The area of an articulating surface on such an enlargement was divided into small stripes of equal width (4 mm.) parallel to one co-ordinate axis. Then the area of each stripe was determined. These area stripes, thought of as having weight, were replaced by a parallel force system in which the magnitude of each force was equal numerically to the area of the corresponding stripe. These forces act vertically through the center of the stripe. A force polygon was drawn from these forces. Then a string polygon was made that gave a point on the action line of the resultant of the parallel force system formed by the center lines of the parallel stripes. The distance of this line from a line parallel to the above-chosen co-ordinate axis and through the reference point with its known position gave, after accounting for the enlargement employed, one co-ordinate of the centroid The other co-ordinates of the centroid were determined by dividing the projection of the joint area in stripes parallel to the other co-ordinate axis and repeating

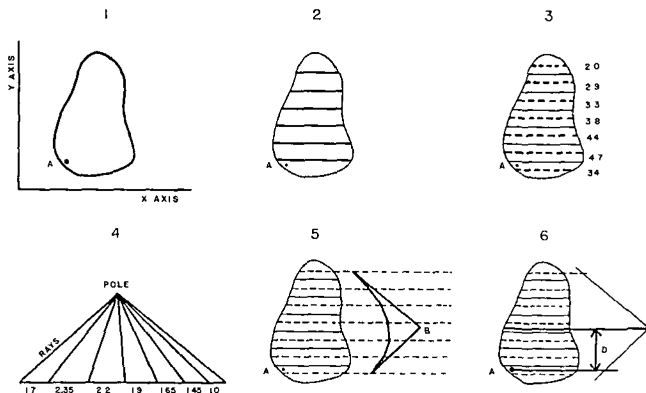


FIG. 2. Step-by-step outline of the graphic method employed for the calculation of one co-ordinate of the centroid of an articulating surface. Each new step is drawn in thick lines.

Step 1 The contour of the projection of an articulating surface in the xy plane is outlined Point A is a checkpoint, the co-ordinates of which were measured.

Step 2. The outlined area is divided into stripes of equal width parallel to the x axis The stripes in the drawing were made excessively wide for reasons of clarity.

Step 3. The areas of the individual stripes were estimated by multiplying the length of the dotted center line through the stripe with its width

Step 4 In order to perform the force polygon, the values of the areas of the individual stripes are marked according to scale (a scale of one half was used in the drawing) on a line parallel to the stripes The position of the pole can be selected arbitrarily at any point. Then the rays are drawn from the pole to the points on the line marked previously.

Step 5. The string polygon is performed by first drawing two lines, parallel to the rays marking the value 1.7, from the center line of the corresponding stripe (3.4). Then another line is drawn, parallel to the next ray that borders the value 2.35 from the center line of the corresponding stripe (4 7). This procedure is repeated until the last line is drawn to meet the first line, which gives Point B

Step 6 The line D is the distance between a line parallel to the stripes through Point B and Point A The y co-ordinate of the centroid can be calculated from its distance D from Point A, the co-ordinates of which are known by measurement

the whole procedure described. These procedures were repeated until the co-ordinates of the centroids of all articulating surfaces of the foot skeleton had been obtained. The table on page 51 gives these values. In those cases in which simple inspection did not permit a safe judgment of the presence or the absence of bony substance between any two centroids, a special gadget devised for this purpose was employed A five-times linear enlargement was employed for the models. The spatial positions of all centroids of one bone were established with a large co-ordinate measuring apparatus built specially for this purpose and marked in a template. Then the correct centroids were

Co-ordinates of the Centroids of the Articulating Surfaces of a Left Foot

Articulating Surface	X cm.	Y cm.	Z cm.
Talocrural	9.99	4.96	7.33
Talonavicular	12.81	6.13	5.25
Posterior talocalcaneal	9.28	4.65	4.69
Middle talocalcaneal	10.85	6.50	3.90
Anterior talocalcaneal	12.35	4.95	3.96
Tuber calcanei, area of contact	7.20	4.50	0
Calcaneocuboid	12.92	3.76	3.19
Navicular-cuneiform I	14.23	6.76	4.64
Navicular-cuneiform II	15.00	5.64	5.50
Navicular-cuneiform III	14.51	4.69	5.07
Cuboid-cuneiform III	14.51	3.69	4.14
Cuneiform I-cuneiform II	15.98	6.63	4.82
Cuneiform II-cuneiform III	15.04	5.04	4.76
Cuneiform I-metatarsal I	16.85	7.14	3.49
Head of metatarsal I	21.05	8.40	1.10
Cuneiform I-metatarsal II	16.74	5.97	4.63
Cuneiform II-metatarsal II	16.28	5.39	4.22
Head of metatarsal II	21.40	6.50	0.72
Cuneiform III-metatarsal II sup. facet	16.14	4.72	3.83
Cuneiform III-metatarsal II inf. facet	15.10	4.70	2.45
Cuneiform III-metatarsal III	16.26	4.72	3.83
Head of metatarsal III	21.30	5.30	0.72
Metatarsal II-metatarsal III	16.76	4.56	3.82
Cuneiform III-metatarsal IV	15.90	3.85	3.00
Metatarsal III-metatarsal IV	16.44	3.94	3.13
Cuboid-metatarsal IV	15.53	3.39	2.42
Head of metatarsal IV	21.20	3.75	0.78
Cuboid-metatarsal V	14.65	2.59	2.17
Head of metatarsal V	19.90	2.70	0.74
Metatarsal IV-metatarsal V	15.68	2.82	2.51

connected by brass rods and joined by solder These procedures were repeated for the stress structures of every bone. Finally, the individual stress structures of the bones were assembled in a complete model.

It is necessary for the evaluation of the models to define those characteristics of the stresses displayed. The characteristics that determine a force or stress are as follows:

1. The magnitude indicates how hard a force pushes or pulls.

2. The direction shows whether a force acts up or down, left or right.

3. The point of application determines where the force acts.

4. The action line contains the point of application and is the line along which the force acts.

The points of application (No. 3) of the concentrated stresses on the articulating surfaces are their centroids. Their positions were calculated. The rods connecting the centroids represent the action lines (No. 4) of the concentrated stresses. The models display, then, the characteristics of forces given under No. 3 and No. 4 but do not furnish information about the magnitude and the direction of the stresses. The direction (No. 2) of some of the stresses can be determined easily and safely by using our experience with forces in our daily life. However, this procedure cannot be employed for any estimation of the magnitudes (No. 1) of the stresses.

RESULTS

When the presence or the absence of the concentrated stresses between the centroids

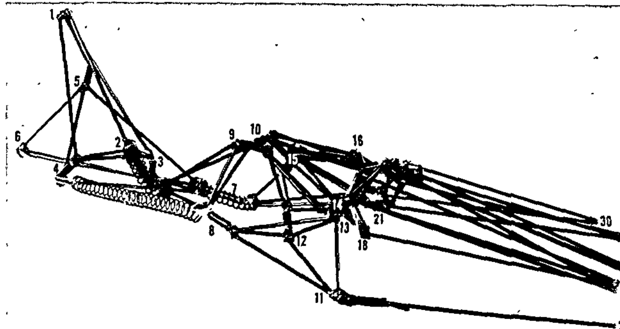


FIG. 3. Anteromedial view of Model 1 collapsed at Chopart's joint. Thin rods represent the short-range stresses that form the stress structures within the bones. Short, thick rods represent spacers between bones Chopart's joint has spring-loaded connections. The spring between talus and navicular can counteract the weight of the model and thus maintain it in a normal position. The centroids of the individual joints and areas are numbered, and their key is given below. The same key is used for the figures of the other models

(1) Talocrural, (2) talonavicular, (3) anterior talocalcaneal; (4) middle talocalcaneal; (5) posterior talocalcaneal; (6) tuber calcanei; (7) calcaneocuboidal, (8) navicular cuneiform I; (9) navicular cuneiform II; (10) navicular cuneiform III; (11) cuneiform I metatarsal I; (12) cuneiform I cuneiform II; (13) cuneiform I metatarsal II; (14) cuneiform II metatarsal II, (15) cuneiform I cuneiform III; (16) cuneiform III sup. facet metatarsal II, (17) cuneiform III metatarasal III; (18) cuneiform III inf. facet metatarsal II; (19) cuneiform III metatarsal IV, (20) cuneiform III cuboid, (21) cuboid metatarsal IV; (22) cuboid metatarsal V; (23) metatarsal II metatarsal III; (24) metatarsal III metatarsal IV; (25) metatarsal IV metatarsal V; (26) head of metatarsal I; (27) head of metatarsal II, (28) head of metatarsal III; (29) head of metatarsal IV; (30) head of metatarsal V.

was determined, it became clear that two different types of concentrated stresses could be distinguished, depending on the choice of the centroids If the centroids are taken from one bone only, the concentrated stresses possible between its centroids represent the stress structure of this bone. However, the centroids can also be taken from different bones, and concentrated stresses can be established so long as there is a substrate (bone and cartilage) along their paths. Such stresses traverse one or more joints and are part of the stress structure that links the different bones together. The first type of stresses was termed short-range stresses a the latter ones long-range stresses.

Model 1 (Fig. 3) displays only the sho range stresses and Model 2 (Figs. 4 & only the long-range ones; Model 3 (Figs. & 7) shows simultaneously both types stresses. An anteromedial view of Model which is collapsed at Chopart's joint (tal navicular, calcaneocuboidal joints), is shov in Figure 3. The stress structures of tl individual bones are formed by the thinn rods and are separated from one another l thicker spacers, except at Chopart's joir Here the spacers are converted to flexib

connections, the significance of which is explained later. The only sites of this model where its configuration permits the recognition of remnants of the lateral and the medial arches are at Chopart's joint. Here are the only connections, medial and lateral, between the hind part of the foot, consisting of talus and calcaneus, and the fore part of the foot. Model 2 shows only the long-range stresses. A dorsal view is presented in Figure 4 and an anteromedial view in Figure 5. The central part of the model displays an agglomeration of these stresses that extend from the tarsometatarsal joints to the anterior and the middle talocalcaneal joints and to the calcaneocuboidal joint. It can be observed that the stresses radiate from each of these latter joints to the whole width of the foot at the tarsometatarsal level. Remnants of a medial and, perhaps, a lateral arch are again detectable in the stress configuration. One can recognize a few long-range stresses that are arranged along a medial path, extending from the tuber calcanei via the talocrural joint to the head of metatarsus I, and other stresses that follow a median to lateral path and extend down from the talocrural joint, not into the head of metatarsus V but into that of metatarsus IV.

Model 3 displays simultaneously the short- and the long-range stresses. The short-range stresses are represented by the darker stained rods and the long-range stresses by the lighter stained rods. An anteromedial view is shown in Figure 6 and an anterolateral view in Figure 7. There is a maze of stresses in the tarsal region and a relative paucity of stresses in the hind part of the foot. However, the posterior border of this maze of tarsal stresses is not at the medial division of Chopart's joint (talonavicular), as might be expected, but at the anterior and the middle talocalcaneal joints and laterally at the calcaneocuboidal joint. In the upper and posterior medial half of the foot there is detectable some orientation

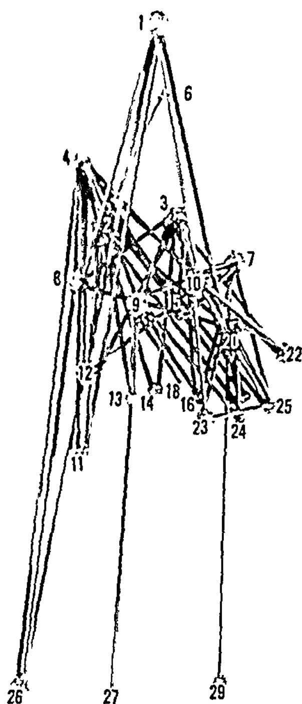


FIG 4 Dorsal view of Model 2. The rods represent long-range stresses between different joints. For key to the numbers see Figure 3.

of a few stresses parallel to the longitudinal axis of the foot. Notwithstanding this occurrence, the general arrangement of the stresses does not permit the recognition of a separate structural medial, lateral or transverse arch. The stress structure of Model 3 has to be defined, in accordance with the

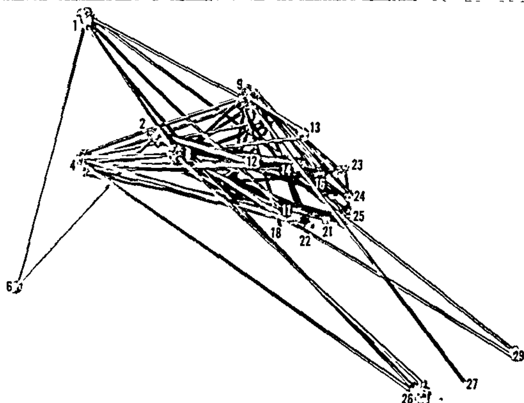


Fig. 5. Anteromedial view of Model 2. The rods represent long-range stresses. For key to numbers see Figure 3.

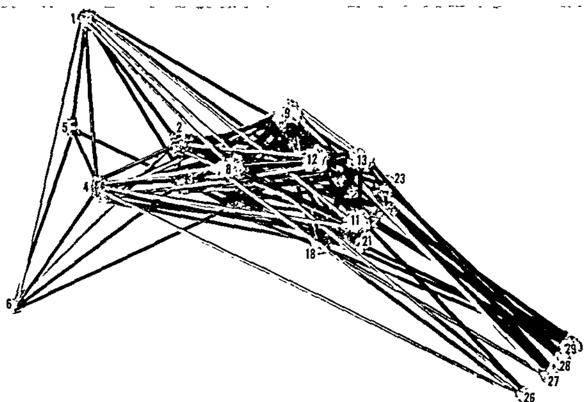


Fig. 6 Anteromedial view of Model 3. Dark rods represent short-range stresses, light rods, long-range stresses For key to numbers see Figure 3.

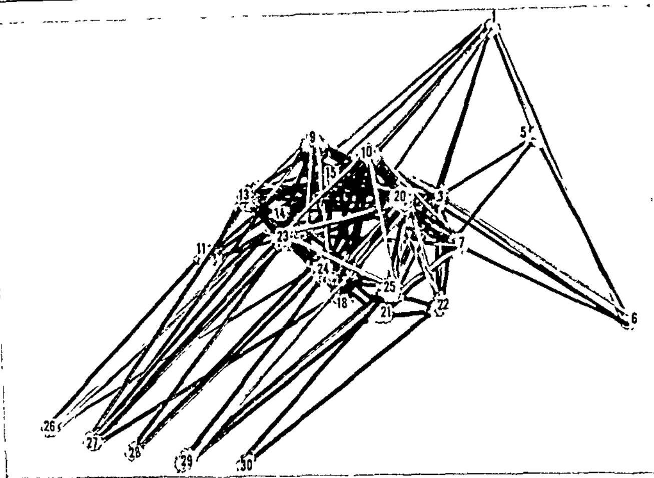


FIG. 7. Anterolateral view of Model 3. Dark rods represent short-range stresses; light rods, long-range stresses. For key to numbers see Figure 3.

laws of analytic mechanics, as a statically indetermined space framework.

INTERPRETATION AND DISCUSSION OF THE RESULTS

One result of the new method employed is the emergence of a new concept of a statically indetermined space framework as the working stress structure of the foot skeleton. Another result is the obvious conclusion that this stress structure consists of two different types of stresses. Due to its complexity, the functional implications of Model 3 are not readily understood. Accordingly, it is advantageous to analyze first some of the functional meaning of the simpler models, 1 and 2.

Model 1, consisting only of short-range stresses, was loaded at the centroid of the talocrural joint. The model collapsed under the load at Chopart's joint, and its metatarsals became flexed at their tarsometatarsal connections in a dorsal direction. The spring-loaded connections at Chopart's joint of Model 1 (Fig. 3) enhanced this observed characteristic and caused this model to collapse even under its own weight. At the talonavicular joint the forces of action meet; i.e., the body weight, acting through the stress structure of the talus, and the forces of reaction, acting through the stress structure of the navicular. The spatial relationship of these two stress structures (as shown in Fig. 8A) is such that the resultant force pushes in a plantar direction. The spatial relationships of the stress structures of the cuneiform I-metatarsal I joint are shown in Figure 8B. It may readily be seen that such a relative arrangement of neighboring stress structures provides for an easy collapse of the joint but not for any stability. Space prohibits showing how the other joints, as

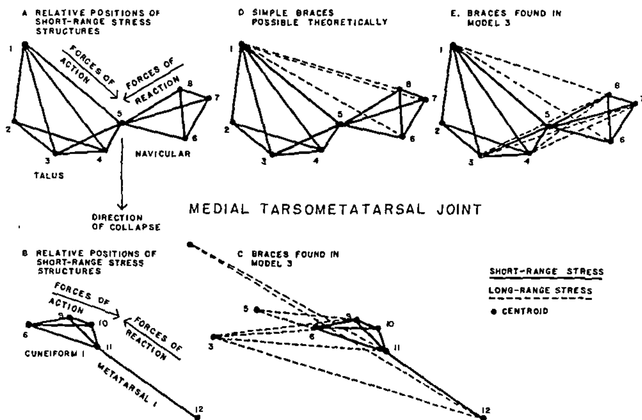


FIG. 8. Modes of the initiation and the counteraction of joint movements by short- and long-range stresses, respectively. Key to the numbers that represent the centroids of *articulating surfaces: (1) talocrural; (2) posterior talocalcaneal; (3) middle talocalcaneal;* (4) anterior talocalcaneal; (5) talonavicular; (6) navicular cuneiform I; (7) navicular cuneiform II, (8) navicular cuneiform III; (9) cuneiform I cuneiform II; (10) cuneiform I metatarsal II, (11) cuneiform I metatarsal I; (12) head of metatarsal I

the calcaneocuboidal and the remaining tarsometatarsal, are also prone to collapse, some more, some less, due to the spatial relationships of the stress structures involved in these joints. It is apparent then from Model 1 that the arrangement of the stress structures involved in certain joints, especially the important talonavicular one, is responsible for the initiation of movements in these joints that lead to their collapse. In the event that these working principles of Model 1 prevail, then excessive loads would be put upon the ligaments in order to prevent the collapse of the foot structure. However, since ligaments stretch under excessive loads, as claimed and shown clinically, no guarantee of a permanent maintenance of the foot structure considered anatomically can be given.

The description of the long-range-stress Model 2 deals with the peculiar distribution of stresses that radiate from each of the anterior and the middle talocalcaneal joints and from the calcaneocuboidal joint to the entire width of the distal part of the tarsus The presence of many of these stresses is made possible solely because the bony substances of many of the "irregularities" on the plantar aspect of the foot skeleton provide a substrate for the stresses. These "irregularities," for which no functional meaning in relation to tendons and ligaments is known, have received a new functional significance. A readily deduced func-

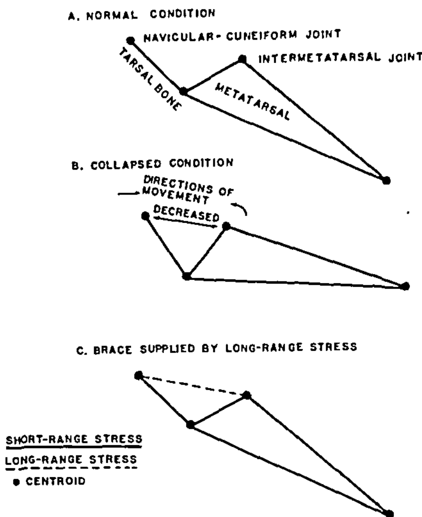


FIG. 9. Bracing function of long-range stresses that counteract collapsibility, induced by short-range stresses, of tarsometatarsal joints II-V.

tion of the radiating long-range stresses mentioned above is the distribution of loads from each of the three joints to the width of the tarsus. This same arrangement of stresses also permits the distribution of loads from any one metatarsus to all these three joints. These functions substantiate Manter's observations of the "transverse compression" of the tarsus and of the "involvement of the tarsal bones in a general transverse direction of the foot in weight bearing." No other functions can be deduced from a structural analysis of Model 2.

A general working principle comparable with that of Model 1 cannot be established for Model 2. A possible reason for this surprising lack of working principle of the long-range-stress Model 2 could be the fact that the existence of these stresses is secondary to that of the short-range stresses. By definition, long-range stresses are those which traverse two or more bones, each of which contains its own short-range-stress structure. This essential dependence of the long-range stresses on the short-range ones could also extend to the respective functions of these stresses. Accordingly, the question of the interaction between the two types of stresses is raised, and the answer to it may provide a working principle of Model 2.

In Model 1, the spatial orientations of the short-range-stress structures of the bones involved in the formation of tarsometatarsal joints II to V were responsible for their tendency to collapse. The centroids of these joints move during a collapse in a plantar direction, thereby forcing the metatarsals into a position parallel to the ground plane.

These movements cause a dorsally obtuse angulation between the tarsus and the metatarsus and entail also a shortening of the distance between the centroids of the intermetatarsal joints and those of the navicular-cuneiform joints. A schematic representation of these conditions is shown in Figure 9A and B. Here it can readily be seen that a brace placed between the centroids of an intermetatarsal and a navicular-cuneiform joint (as shown in Figure 9C) will prevent the collapse of the tarsometatarsal joints. This theoretically predicted barrier against collapsibility of the tarsometatarsal joints II to IV actually is present in Model 3. The gray-colored long-range stresses that act as braces between the navicular-cuneiform and the intermetatarsal joints are shown in Figures 6 and 7. The geometric figures of triangles formed by the concentrated short- and long-range stresses are shown in Figure 8. The arrangement is a simple trusslike one, because the triangles of Figure 9 all lie in one plane, as required by the classic definition of a truss. Model 3 displays also triangles that are formed by the short-range stresses within the cuneiforms and the metatarsals and those formed by the long-range stresses between the intermetatarsal and the navicular-cuneiform joints. Since all these triangles lie in different planes and are joined at the centroids, the arrangement can no longer be called a simple trusslike one but must be defined as a space framework. Such a space framework of all stresses possesses highly complex and fine interactions between its individual parts. However, this observation does not alter the concept of bracing of the metatarsals by long-range stresses The implication is that the bracing action is not a simple one but a highly complex action exerted through a space framework of stresses In conclusion, it can be said that the stabilization of the tarsometatarsal joints II to V is effected by the simple device of bracing. The most basic and, in engineering technic, most often used configuration of stresses—the triangle—is utilized for the bracing action. But these triangles are utilized to establish a complex space framework. Even though a detailed quantitative analysis of the working of the space framework involved was not undertaken, one can reasonably be assured that such a complex stress mechanism would be capable of producing the finer phases of adaptation of the metatarsals to their different positions observable in the living foot.

The precarious configuration of the short-range stresses that meet at the cuneiform I-metatarsus I joint and the latter's inherent instability have already been mentioned. Several triangles formed by the stresses are in functional association with this joint, as shown in Figure 8C. The general supporting function of these long-range stresses can be deduced from Figure 8C. The actual supporting action is more complicated, because these triangles are, again, part of a space framework.

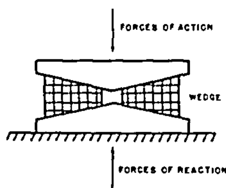
The instability of Chopart's joint in Model 1 was emphasized. The collapse of its talonavicular division causes (as can be deduced from Figure 8A) a decrease of the distance between the centroids of the talocrural joint and those of the navicular-cuneiform joints. The prevention of this decrease by braces (as shown in Figure 8D) between the afore-mentioned centroids will stabilize the joint in a fashion similar to that observed for the talometatarsal II to V joints. Indeed, long-range stresses of Model 3 exert bracing actions, but they are arranged in a different manner from that predicted. According to prediction, only the centroids of the navicular-cuneiform I and navicular-cuneiform *III* joints are braced to the centroid of the talocrural joint. Additionally, the centroids of the navicular-cuneiform II and III joints are both braced to the centroids of the anterior and the middle talocalcaneal joints (Figure 8E). The centroid of the navicular-cuneiform III joint has a separate brace to the calcaneocuboidal joint, thus linking the two divisions of Chopart's joint.

The other division of Chopart's joint—the calcaneocuboidal joint—had also collapsed in the weight-loading experiments described. But, surprisingly, no long-range stresses could be detected in Model 3 that could be interpreted as possessing real and direct bracing actions or an action similar to the one found at the cuneiform-metatarsus I joint.

This first analysis of the interactions between the two types of stresses indicates that the long-range stresses supplement and counteract the actions of the short-range stresses. The device of a bracing mechanism was used to stabilize the tarsometatarsal II to V joints and the talonavicular joint. More extensive and more efficient bracing mechanisms could be devised theoretically for these joints and also for the calcaneocuboidal joint that did not possess any bracing mechanism. However, the configurations of the bones did not permit these devised mechanisms to operate as they should have. The importance of Chopart's joint and of the cuneiform I-metatarsus I joint for the integrity of the foot gives rise to the speculation that there still may be other protective mechanisms at work.

The long-range stresses, according to their definition, traverse joints, and it is this characteristic on which another protective mechanism is based. One long-range stress extends from the talocrural joint to the head of metatarsus I and traverses navicular-cuneiform I and cuneiform I-metatarsus I joints. This long-range stress transmits downward parts of the body weight that then is met by its force of reaction at the head of metatarsus I or at any other location along the extent of this stress. The navicular and cuneiform I bones, being sandwiched between talus and metatarsus I, are squeezed and kept in their position by these forces of action and reaction. It is an action similar to the one used by a person moving as a solid mass several books from one shelf to another one. If the books are squeezed hard enough, no book will slip out during the transfer. This squeezing action is not limited

SELF-LOCKING WEDGE MECHANISM



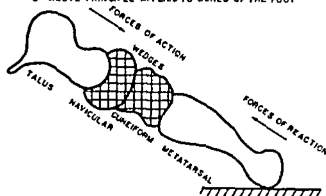


FIG. 10. Self-locking wedge mechanism. The wedges of "A" cannot be driven out even by largest magnitudes of the forces of action and reaction.

to the long-range stress just described. Any other long-range stress that traverses the joints will also effect this action. A closer observation of Model 3 reveals that there are 19 such stresses for the talonavicular joint, 7 for the navicular-cuneiform I joint, 6 for the calcaneocuboidal joint, and so on. All joints possess this property of being crossed by long-range stresses except those which connect the lateral and the medial parts of the foot; i.e., cuneiform II-cuneiform III, cuneiform I-metatarsus II, metatarsus II-cuneiform III, metatarsus I-metatarsus III, cuneiform III-metatarsus IV. It seems significant that the largest number of the protective traversing long-range stresses are found at the most labile joint of the foot; viz., the talonavicular joint. The fact that these stresses have all different directions, some decidedly, others only slightly, different from each other, leads to the speculation

that this arrangement may be connected with the protection of the joint at different positions.

The principle underlying this squeezing action is an old one and is known in mechanics as that of the self-locking wedge. This is a wedge that under certain conditions will not slip out under its load. Figure 10A shows such a device, and Figure 10B shows the application of this principle to some bones of the foot skeleton. Figure 11 pre*sents a demonstration of this principle,* producing what might appear to be a "mechanical impossibility." The surfaces of the three individual pieces of hard wood within the clamp were sanded smoothly. The pieces are pressed together as tightly as possible by the clamp. The weight suspended on the "inverted keystone" amounts to 4,500 Gm. On a wedge used in simple technical applications the surfaces thereof are plane. However, the "wedges" formed by many bones

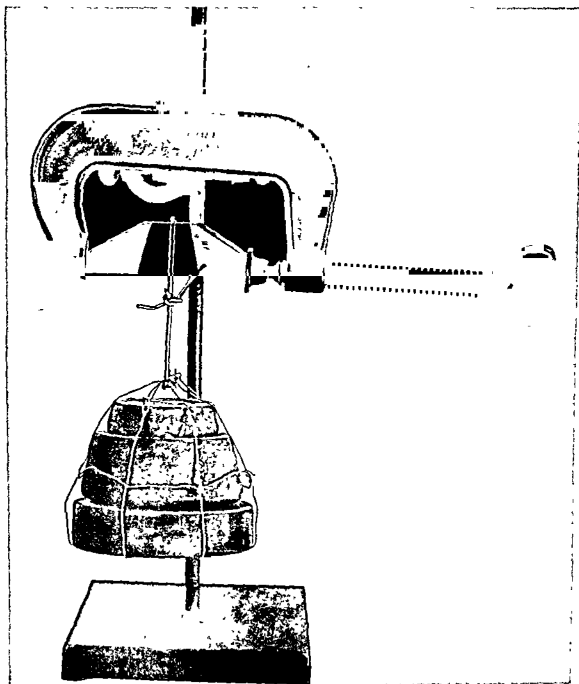


FIG 11 A "mechanical impossibility" produced by the self-locking wedge mechanism

possess curved surfaces. This attribute and the changing positions of the bones relative to each other not only complicate future detailed analysis but also may produce some modifications of this self-locking principle.

An analysis of the interactions between short- and long-range stresses made on some major joints revealed the following modes of interaction: the bracing type, the utilization of the basic element of the trusses, the triangle in a space framework and the device of a self-locking wedge. Seemingly, then, there is no common mechanism for all joints since each joint has its own functional mechanism for specific needs. The individual long-range stresses also possess multiple functions exerted simultaneously. They distribute weight from one side of the foot to the other, they link up with other stresses (short or long ones) to form bracing mechanism, and they traverse joints, thus participating in action of the self-locking wedge.

The knowledge of the functions of the short- and the long-range stresses warrants a concept about the simultaneous establishment of the two seemingly incompatible properties of the foot, its resiliency and its stability. The short-range stresses are responsible for the resiliency, as they initiate movements of the joints in the direction of the "give" that is observed in the living foot. The long-range stresses are responsible for the stability, as they counteract and control the destructive tendencies of the short-range stresses. The two types of stresses are initiated by the loads of the body weight and are present simultaneously. It is the interplay of these stresses that produces the simultaneous existence of resiliency and stability. Undoubtedly, however, this simple concept will have to be modified after more pertinent detailed studies have been made. The simple concept outlined is far better considered anatomically than the rather vague explanations in current textbooks.

The stress structure of Model 3 was classified as a statically indetermined space framework. It is defined in mechanics as possessing superfluous members; i.e., more members than are necessary to do a certain job, each member carrying smaller loads and, therefore, being lighter in structure. This finding substantiates the often-expressed opinion that the skeleton of the foot is relatively light for its task. The space framework of the foot is also a more complicated one than those used in the technical world. These are constructed for one particular function only, as the stability of a radio transmission tower, or an air frame, or the weight-carrying ability of a modern bridge. The space framework of the foot, however, can perform two seemingly incompatible functions of resiliency and stability.

Hicks (1955)[4] advanced the concept that the plantar aponeurosis through its tie action was the essential structure for the establishment of the foot structure. In view of the importance of this concept, the relation of the plantar aponeurosis to the stress mechanics presented will be considered. The long-range stresses shown in Figure 10 exert the self-locking wedge function on the navicular and the cuneiform I. The body weight acts as a force of action along this stress, and it has at the metatarsal head a forward-pushing component that tends to move the head forward. If its friction with the soft tissues and with the ground is insufficient, the metatarsus will slide forward. This sliding makes inactive the forces of reaction on which the self-locking wedge action depends, and the short-range stresses will collapse the structure. It was shown by Hicks that the plantar aponeurosis was under tension during weight-bearing and, therefore, was necessary for the fixation of the metatarsal heads. Hicks's concept of the plantar aponeurosis acting as a tie between calcaneus and metatarsal heads can be expanded. The plantar aponeurosis ensures the effective interplay between short- and long-range stresses and the self-sustaining functions of the latter.

The stress models present a new concept of the mechanics of the foot skeleton. They are also capable without further detailed

analysis of explaining some clinical phenomena. A fracture of the calcaneus occurs easily in persons standing in falling elevators or jumping from great heights. The sudden deceleration puts enormous loads on the foot. Model 3 shows that there are only four short-range and two long-range stresses in the calcaneus. All these stresses converge to the small area between the lateral and the medial tubercles. This arrangement does not permit a distribution of the loads in a multidirectional way. The immense magnitudes of the stresses produced by the sudden deceleration are concentrated upon the few converging pathways in the calcaneus. This concentration causes strains of such magnitudes that the bone breaks. Another clinical experience is that the crushability of the foot is greater from lateral to medial side, or vice versa, than from the anterior to the posterior side. Models 2 and 3 (Figs. 6 & 7) show that the long-range stresses run in varying degrees obliquely to the longitudinal axis of the foot, forming an arrangement that resembles a lattice. The external forces that act from the lateral to the medial side tend to squeeze these oblique stresses parallel to the longitudinal axis. This movement can be compared with the closing of an extension lattice gate in which the crossed stripes assume a more vertically inclined position when closed The long-range-stress arrangement does not produce great resistance to the external forces directed laterally and medially. However, when the external forces act from the anterior side, they become distributed over the whole width of the foot according to the arrangement of the long-range stresses Accordingly, a spreading of the foot could be induced but no squeezing together of its parts The metatarsus II is known to be the most stable one. Model 3 confirms this anatomic finding and conclusion of clinical experience by revealing *13 short-range and 2 long-range stresses* within this metatarsus, the largest number within any metatarsus

This observation helps to explain phenomena associated with the shortness of the *first metatarsal, which characteristic* was advanced by Morton (1952[8] and earlier) as a causative factor for the "fallen metatarsal arch" with consecutive transfer of a larger amount of body weight to the second metatarsal. The resistance of the metatarsal II-cuneiform II joint against collapse by such increased weight-bearing loads can be readily understood with the aid of the models. The many short-range stresses distribute the loads to all the articulating surfaces at the base of the second metatarsal. The two long-range stresses exert the self-locking wedge effect across its articulation with the second cuneiform. Its intermetatarsal joints are braced, as described, by long-range stresses against the navicular-cuneiform II and III, the cuneiform III-cuboid and the metatarsal IV-V joints Other long-range stresses, already described in connection with Model 2, transmit loads from the base of the second metatarsal to the middle and the anterior talocalcaneal joints and to the calcaneocuboidal joint. These long-range stresses traverse the cuneiform II and III bones and their articulations with the navicular. The self-locking wedge effect is thereby brought into play on these latter joints, and the two cuneiform bones are made more stable in their place. An experimental shortening of the first metatarsal of the skeleton used for this investigation would eliminate the bony continuity for the long-range stress between the head of the first metatarsal and the middle talocalcaneal joint. The elimination of this long-range stress extending between the points No 3 and No. 12 of Figure 7C reduces the supportive trusslike arrangement for the cuneiform I-metatarsal I joint. Studies on foot skeletons with a genuine short first metatarsal are necessary to confirm or modify this hypothesis

As evidenced in this investigation, the application of a new method to an old problem revealed a newer concept of the foot skeleton working as a statically indetermined space framework. Its mechanics are strikingly unique, as was surmised by the earlier investigators quoted in the introduction.

Anatomically considered, the new concept provides a better explanation and understanding of the most diverse and perplexing characteristics of the foot; viz., its resiliency and stability. With the new concept, some clinical phenomena now can be more readily understood and explained. Finally, it is quite obvious that the new concept poses many new problems, with the result that the mechanics of the flat foot, the pes talipes and the different positions of the talonavicular joint and of the ligaments will have to be restudied with the aid of this new approach.

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Le Mechanica del Pede, Basate Super le Concepto del Skeleto Como un Staticamente Non Determinate Structura Spatial

Summario in Interlingua

Le validitate del ancian conception del skeleto del pede como essentialmente un arco es testate per le application del methodos de mechanica analytic. Le principio simplificatori de iste methodos es le reduction del distribuite tensiones, que age inter le superficies articulatori del ossos, a un schema de tensiones concentrate. Le puncto de application del fortia de un tension concentrate al superficie articulatori es su centroide Su position con respecto a un systema de coordinatas applicate al total skeleto del pede pote esser calculate per medio de un methodo graphic. Le representation del tensiones concentrate per barras metallic permitte le construction de simplificate modellos del tension in le skeleto del pede Duo differente typos de tension pote esser differentiate. Tensiones vicinal es active solmente intra le ossos individual. Tensiones distantial transversa duo o plure ossos e un o plure articulationes. Esseva construite modellos representante le tensiones vicinal, le tensiones distantial, o tensiones de ambe typos. Experimentos con cargas de ferro in tal modellos permitte le deduction que le structure de tensiones vicinal tende a collaber al sitos de su articulationes in le direction del resilientia natural del pede. Iste tendentia es supplementate e contrariate per le tensiones distantial que se servi pro iste objectivo de un mechanismo de consolas, transversos, e cuneos a blocage automatic. Le combinate structura tensional del duo typos de tensiones non resimila un simple arco conventional sed representa un staticamente non-determinate structura spatial. Es stipulate como hypothese que le structura del tensiones vicinal es responsabile pro le resilientia del pede e le structura de tensiones distantial pro su stabilitate. Plure phenomenos clinic pote esser explicate immediatemente per iste nove mechanica. Del altere latere, illo subleva multe nove problemas.

8

The Pathomechanics of Peroneal Spastic Flat Foot*

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and
IAN D. MURPHY, M.D.‡

A renewed interest in the subject of peroneal spastic flat foot has been apparent in both American and British literature since publication in 1948 of an article by Harris and Beath[4] that gave promise of solving the puzzling nature of this disease. They described a new radiographically demonstrable tarsal anomaly—talocalcaneal bar—in most of their cases and focused attention again on the earlier articles by Sloman[10] and Badgley,[1] who had found calcaneonavicular bar in association with rigid or spastic flat feet. Subsequently, in 1955, Harris[3] described incomplete talocalcaneal bar that could not be shown by radiographs but resulted in spastic flat foot and could be demonstrated at operation. In 1955,[8,9] two more tarsal anomalies were found to be associated with peroneal spastic flat foot; i.e., calcaneocuboid bar and posterior talocalcaneal (trigonal) bar. Since in each of these five instances a bar occurred at a site at which tarsal ossicles appeared, at times it was tempting, if not entirely plausible, to assume that fusion of an ossicle to two tarsal bones resulted in the bar.

In view of the foregoing, it seemed that *it was possible at last to generalize regarding* the etiology of idiopathic (i e., nonrheumatic) spastic flat foot by stating that tarsal anomalies produced by fusion of an ossicle to two or more contiguous bones could so upset the mechanics of the foot as to produce a rigid or spastic flat foot. Theoretic objections to this concept have been advanced by several authors, and, more importantly, cases of spastic flat foot not involving anomalies that could be produced by tarsal ossicles have been found. To date, the following conditions have been implicated:

1. Congenital
   A. Tarsal anomalies
      a. Intertarsal bridges, possibly mediated by an accessory tarsal bone
         (1) calcaneonavicular bar
         (2) anterior talocalcaneal bar (talosustentacular)
         (3) calcaneocuboid bar
         (4) posterior talocalcaneal bar
         (5) malformation of the sustentaculum or of the talus that acts as a block to motion
      b Tarsal synostoses due to incomplete segmentation
         (1) combined anterior and posterior talocalcaneal synostosis
         (2) combined tarsal and phalangeal (hand) synostosis
         (3) calcaneocuboid, talosustentacular and posterior talocalcaneal synostosis and scoliosis
      c. Anomaly of the scaphoid
   B. Osteochondrodystrophy (Morquio's disease)
2. Acquired
   A. Gallie subtalar arthrodesis (Harris)
   B. Tuberculosis of tarsus (Jack; Howorth)
   C. Rheumatoid arthritis involving the tarsus

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FIG. 1. Changes at the talar head characteristic of congenital form of peroneal spastic flat foot.



FIG. 2. Calcaneonavicular bar with beaking

D. Osteoarthritis superimposed on a burned-out rheumatoid arthritis (Jack)
E Nonspecific tarsal synovitis (Howorth)
F Trauma (Jack; Howorth)
G. Occupational strain (Jack)

While some of these may be of questionable authenticity or may represent unrecognized tarsal anomalies, elimination of the doubtful ones still leaves a considerable number of such apparently unrelated conditions that it seems impossible to find a common denominator for them. The task is not made easier by the fact that certain of these conditions may always produce a rigid but asymptomatic foot while others may produce a painful foot accompanied by peroneal



FIG. 3. Calcaneonavicular bar without beaking.



FIG. 4. Osteoarthritis of ankle and tarsus The joint spaces are thin and their margins sharpened. The spur at the talar head is small.

spasm on one side and, perhaps, a symptomless and to the patient a normal foot on the other. The "normal" foot may or may not eventually become painful.

It is our belief that the key to the solution is to be found in the characteristic radiographic changes seen at the head and the neck of the talus in spastic flat feet (Fig. 1). With some of the conditions listed as etiologic factors, these changes are not seen, and, while the feet are rigid, pain and peroneal spasm do not occur. With others—notably calcaneonavicular bar (Figs. 2 & 3)—the changes may or may not be present, and the feet may or may not be symptomatic. In the case of the talosustentacular bar and the posterior talocalcaneal bar, in our experience the changes are always seen and in general are of greater magnitude than when associated with other anomalies From these facts it becomes apparent that a distinction must be made between rigid flat feet and peroneal spastic flat feet. Rigid flat foot may be only a stage in the evolution of spastic flat foot, or it may exist and persist as a clinical entity.

NATURE OF THE CHANGES AT THE TALONAVICULAR JOINT

Most recent authors have commented on the radiologic changes found at the talar head and neck and, to a lesser degree, at the upper proximal articular margin of the navicular. These have been designated variously as "beaking," "lipping" or "spurring." By direct statement, or by implication, they have been regarded as evidence of a localized osteoarthritis. However, it should be remembered that osteophyte formation is only one of the radiographic manifestations of degenerative arthritis. Smyth[6] lists the early findings as follows (Fig. 4):

1. Narrowing of the joint space (due to thinning of the joint cartilage)
2. Sharpening of the articular margin
3. Formation of bony spicules and osteophytes at the margin of the joint
4. Slight tilting of one bone on another because of irregularities along the bony joint surfaces
5. Atrophy of disuse at the ends of the bones in some cases.

Judged by these standards it is apparent that the so-called beaking at the talar head is not a manifestation of arthritis (Fig. 5). The inordinate size of the spur, its existence alone without other signs of arthritis, or its early rather than late appearance if other manifestations of arthritis are present is evidence of this. Moreover, the spurring occupies a constant dorsal position and is not distributed about the circumference of the

joint, as is usually the case in osteoarthritis.

In a previous issue of *Clinical Orthopaedics*[8] we called attention to the peculiar anatomic relationship between the calcaneus and the navicular. Though these bones do not articulate, they are held in constant relationship by two relatively substantial ligaments; i.e., the plantar calcaneonavicular and the calcaneonavicular portion of the bifurcated ligament. Therefore, the subtalar and the midtarsal joints must work synchronously. For the navicular to glide dorsally over the head of the talus, the calcaneus must first move forward on the talus. With subtalar motion eliminated by a talocalcaneal bar, the navicular exerts pressure on the talar head and molds it into characteristic shape.

Study of ciné-fluorographic films showing dorsiflexion-plantar flexion motions in a normal foot and in a foot that has had subtalar fusion has been made possible by the courtesy of Dr. George Ramsey and his associates at the University of Rochester. In dorsiflexion of the normal foot, the calcaneus can be seen to glide forward on the talus to an appreciable degree until checked presumably by the capsular ligament. Then, very near the end of the dorsiflexion movement, an upward gliding motion is seen, both at the calcaneocuboid joint and the talonavicular joint, and, finally, the wide upper portion of the navicular moves slightly cephalad on the talar head. In the foot with subtalar fusion, gliding motion at the midtarsal joint gives way to hinge motion. In full plantar flexion, the joint fissures of the midtarsal joint widen superiorly and narrow inferiorly, in dorsiflexion, the reverse is true, and, in addition, the sharp upper edge of the navicular impinges on the head of the talus. If one could think of the talar head as having a plastic consistency—as indeed it has before ossification—it is easy to visualize the remodeling, or reshaping, that occurs. Anything that interferes with talonavicular



Fig. 5. Molding changes. The joint space is wide and smooth. The spur is inordinately large.

motion, whether it is a tarsal ossicle that fuses to form a bar, a tarsal anomaly produced by failure of segmentation or one of the several acquired conditions previously referred to, will produce this. Abnormalities that do not seriously affect this motion by preventing or substantially reducing subtalar motion—for example, calcaneonavicular bar —cause only slight interference, merely the motion that normally is permitted between the calcaneus and the navicular by the calcaneonavicular ligaments being lost. If the bar is incomplete (a synchondrosis or syndesmosis) or the bar ossifies late, no alteration in the shape of the talar head may occur, and, at worst, the changes will be relatively slight. In the congenital case, the remodeling begins early in life, but, since the talus is represented at that time by a bony nucleus surrounded by a thick rind of cartilage, roentgenograms are negative (Fig. 6, *top*). It is only when ossification is nearly complete that the typical beak is apparent radiographically (Fig. 6, *bottom*).

While, as noted before, practically every spastic flat foot shows changes of some degree at the talonavicular joint, not every foot

showing such changes is a peroneal spastic flat foot. Thus, it seems logical to state that the molding changes in the talar head are not, in themselves, responsible for peroneal spasm, and some additional factor must be sought. In a previous article[9] we illustrated a case with bilateral talocalcaneal bar with marked molding changes. Both feet were rigid, but only one side was painful and exhibited peroneal spasm. On this side, in

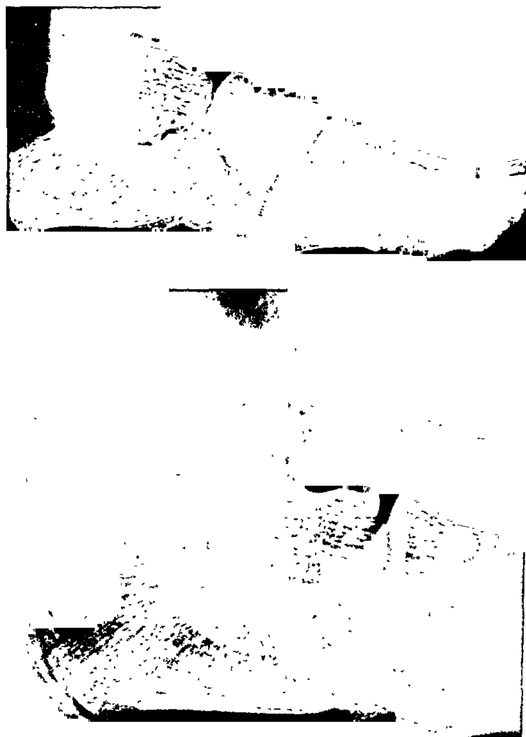


FIG 6, Case G.S (*Top*) At 9 years Calcaneonavicular and talocalcaneal synostosis The talar head is round, since ossification is incomplete. (*Bottom*) At 13 years Ossification is nearing completion, and the characteristic molding changes now are apparent.

addition to the beaking, there were thinning and irregularity of the talonavicular joint; in other words, definite evidence of degenerative arthritis. The implication is clear; i.e., in many, but not all, cases the remodeled talonavicular joint undergoes degenerative changes and becomes painful, and peroneal spasm ensues. Or, in rare instances, acute trauma to which the abnormal talonavicular joint must be particularly susceptible may result in a painful joint and peroneal spasm, though no changes at the talar head are seen roentgenographically. The roentgenograms of such a case are shown in Figure 7. This patient, a girl of 11 years, had been treated conservatively (rest, physical therapy and a full metal arch support) for several years. In spite of this, she had recurrent bouts of pain and spasm to the point at which the mother insisted on definitive treatment. A triple arthrodesis was carried out, and the bone and the cartilage from the excised talonavicular joint was submitted for examination. The report, in part, was as follows:

> Adjacent to these areas with minor deviation from the normal, one encounters at one point an area of bone thickening with increased cellularity suggesting a repair process, and at another point a break in continuity of the surface layer with crowding of the spicules and fibrosis between them. In the fibrotic layer there is also evidence of new bone formation with osteoid spicules infiltrating the fibrous tissue. There is not much inflammatory cell infiltrate at any point. The picture is suggestive of a process of injury and repair.

PERONEAL SPASTIC FLAT FOOT WITHOUT BONE ANOMALY

The foregoing ignores the fact that Jack,[7] Blockley[2] and others have reported cases without demonstrable radiographic abnormality. However, when one recalls the facility with which everyone missed such an obvious lesion as talosustentacular bar until Harris and Beath reported it, the bald assertion that a radiograph is negative will hardly be accorded great weight.

Harris has already given partial answer to this problem in his description of minor variations in the structure of the talosustentacular joint that are not demonstrable radiographically but interfere with tarsal motion and can be visualized at operation.

Another type that may be more common than supposed and easily missed in roentgenographic studies is illustrated by the following case:



FIG. 7. G W, age 11 years There is a calcaneonavicular bar. The foot was painful, and there was peroneal spasm. No changes are seen at the talonavicular joint.

S. N., female, aged 18 years, candidate for nurses' training school, was examined on une 14, 1956 She had no complaints referable o her feet. On grasping the right heel, the alcaneus could be moved freely on the talus in the direction of inversion and eversion. On the left side no such motion could be demonstrated, the hind foot appearing to be rigid. Roentgenographic examination in the lateral projection was reported to be negative except

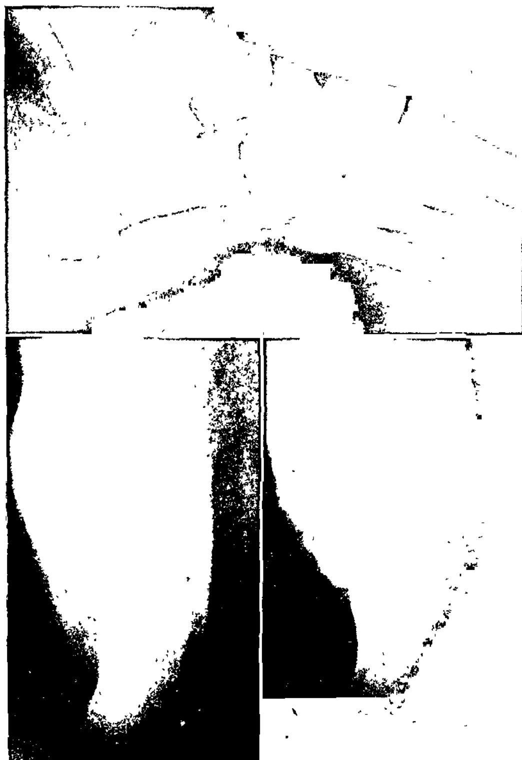


FIG 8, Case S N. (*Top*) There are molding changes at the talonavicular joint No bar is seen (*Bottom, left*) The joint fissures are ... There is a thin plaque of bone bridging the talosustentacular ... *right*) Changing the position of the x-ray ... the ... but does not eliminate it.



FIG. 9 An artificial plaque constructed on a dried articulated skeletal foot.



FIG. 10. Roentgenogram of the artificial plaque.

for lipping at the talonavicular joint (Fig. 8, *top*) The posterior oblique view was reported to be negative (Fig. 8, *bottom, left*). Careful study of these roentgenograms shows that the joint fissures of the talosustentacular and the posterior subtalar joints are, in fact, open and well formed. However, there appears to be a thin plaque of bone bridging the talosustentacular joint medially. It is not the usual broad bar. It was the radiologist's opinion that it was some bony prominence lying anterior to the joint that gave the illusion of a thin bar. Multiple roentgenograms were taken with the x-ray tube in various positions, while the width of the shadow could be changed, it could not be eliminated in any projection (Fig. 8, *bottom, right*) It seems that this is a variant of the *talosustentacular bar similar to John Hunter's* specimen of talocalcaneal bridge reported by Harris and Beath.[5] Confirmation of this was obtained by attaching a beef-bone plaque of appropriate size and shape to the medial aspect of the talosustentacular joint of a skeleton (Fig. 9). The radiographic appearance is identical (Fig. 10).

There is little reason to doubt that if this lesion is at all common, it is missed by the average radiologist without special interest in this subject.

A third type of significant anomaly that might be overlooked is illustrated by another case.

P. O., male, aged 16 years, was examined on July 6, 1959. He stated that he had had painful feet for the preceding 6 years. His symptoms were aggravated by walking and relieved by rest. The left foot was much worse than the right, and there was obvious spasm of the peroneals. Lateral roentgenograms showed rather marked molding changes at the

talonavicular joint, the beaking being greater on the left foot. In the posterior oblique projection, the right foot showed a bony talosustentacular bar (Fig. 11, *left*). The left foot exhibited no such anomaly (Fig. 11, *right*). However, the talosustentacular joint fissure was oblique rather than horizontal in direction and somewhat thin and irregular. There is no reason to doubt that the altered shape resulted in altered function. Yet a radiologist unfamiliar with the posterior oblique view (and many are) might well report the roentgenograms as "negative."

In view of the foregoing, it seems not unreasonable to believe that variations of anatomy in radiographically "inaccessible" locations in the tarsus may explain many of the "normal" feet.

THE ORIGIN OF PERONEAL SPASM

The exact mechanism of peroneal spasm remains a mystery. Most, but by no means all, authors believe it to be reflex muscle spasm. There is little agreement as to the site of the stimulus that produces the spasm and no adequate explanation of its confinement to the peroneals and, rarely, the toe extensors and the anterior tibial muscles.

With the discovery of the talocalcaneal bar as the most frequent anomaly associated with spastic flat foot, it would seem that a painful subtalar joint could be eliminated as a site, since a complete bar prevents motion there. The finding of molding changes at the talonavicular joint as a constant accompaniment, though not the cause of spastic flat foot, strongly suggests this structure as the site or origin. If it could be shown that the sensory innervation of this joint was through the superficial peroneal nerve, which also supplies the peroneal muscles alone, a logical explanation would be at hand. Unfortunately for the theory, the rather meager factual material pertaining to this indicates that the talonavicular joint is supplied by the deep branch of the peroneal nerve, and, from the standpoint of gross anatomy, this seems likely. However, there is no great accumulation of anatomic data to establish this point definitely. Furthermore, is not double innervation a possibility, a few twigs from the superficial peroneal nerve reaching the area of beaking and subsequent wear-and-tear changes even though the deep branch supplies most of the joint? It is by no means impossible that subsequent investigation may prove the explanation of this puzzling phenomenon to be as simple as that.



FIG 11, Case P.O. (*Left*) Left foot. There are pain and peroneal spasm The talosustentacular joint is abnormal, but there is no bar (*Right*) Right foot There is a complete bar. The foot is asymptomatic.

SUMMARY AND CONCLUSIONS

1. The recent tendency to regard tarsal anomalies produced by fusion of tarsal ossicles to contiguous bones as the sole cause of idiopathic peroneal spastic flat foot is not justified.

2. Numerous congenital and acquired conditions have been implicated.

3. A distinction must be made between rigid and spastic flat foot. Rigid flat foot may be one stage in the evolution of spastic flat foot or it may exist as a clinical entity.

4. The effect of all authenticated causes of spastic flat foot is to prevent gliding of the navicular over the talar head in dorsiflexion. Those conditions that eliminate subtalar motion are most potent in this regard.

5. The characteristic beaking of the talar head, found in all spastic and in some rigid flat feet, is a molding change and not evidence of arthritis. In congenital cases, this occurs early but is seen radiographically only with well-advanced ossification.

6. The onset of peroneal spasm in a previously rigid foot is due either to premature arthritic changes in the talonavicular joint or to trauma to which the abnormal joint is particularly susceptible.

7. The exact mechanism of peroneal spasm remains a mystery. A possible explanation is proposed, though factual data to support the theory is lacking.

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Summario in Interlingua

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9

Dynamic Posture in Relation to the Feet

BECKETT HOWORTH, M.D., MED. SC.D.

Posture should be considered as the sum total of the positions and the movements of the body throughout the day and throughout life. It should include, not only the fundamental static positions in lying, sitting and standing, and the variations of these positions, but also the dynamc positions of the body in motion or in action, for it is here thaτ posture becomes most important and most effective. Posture has a direct relation to the comfort, the mechanical efficiency and the physiologic functioning of the individual.

ANATOMIC CONSIDERATIONS

The structural foundation of the foot consists of the 12 tarsal and metatarsal bones. The toes contain 14 small bones, 2 phalanges in the big toe and 3 in each of the others. The bones of the foot are so arranged as to give maximum flexibility and power, in addition to their chief function of supporting the weight of the body. The ligaments bind the bones together and maintain their relations when the foot moves to its various extreme positions. These positions vary with the lengths of the ligaments, which have no power of contraction, are not subject to voluntary control and do not stretch appreciably except under continued or repeated strain. The muscles of the foot control its positions and motions and supply its power. Their tendons serve not only as attachments but also as reinforcement for the ligaments. The tendon of the peroneus longus in particular, passing under the metatarsus, serves to strengthen the transverse arch by acting as a sling or bowstring.

The circulation of the foot is important to its nutrition and muscle action, but, because the foot is dependent, far from the heart and

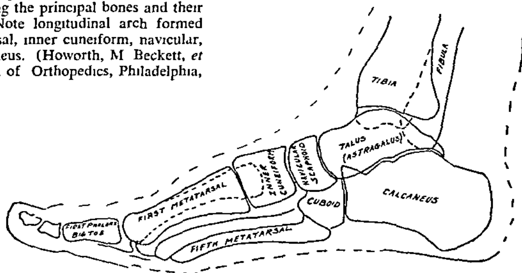


FIG. 1. Tracing from roentgenogram of normal foot showing the principal bones and their relationships. Note longitudinal arch formed by first metatarsal, inner cuneiform, navicular, talus and calcaneus. (Howorth, M Beckett, *et al*. A Textbook of Orthopedics, Philadelphia, Saunders)

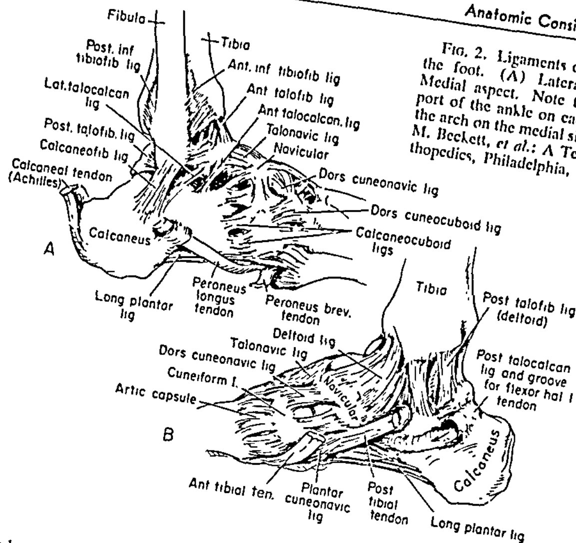


Fig. 2. Ligaments of the ankle and the foot. (A) Lateral aspect. (B) Medial aspect. Note the strong support of the ankle on each side, and of the arch on the medial side. (Howorth, M. Beckett, *et al.*: A Textbook of Orthopedics, Philadelphia, Saunders)

exposed to all kinds of trauma, it is highly vulnerable. Certain types of shoes tend to interfere with the circulation, especially those that are too snug.

The longitudinal arch extends from the heel to the ball of the foot and is higher usually on the inner than the outer side of the foot. This arch varies moderately in the average person with weight-bearing and with changes in foot posture. It varies little in more rigid feet, such as those with high arches, equinovarus club feet and advanced

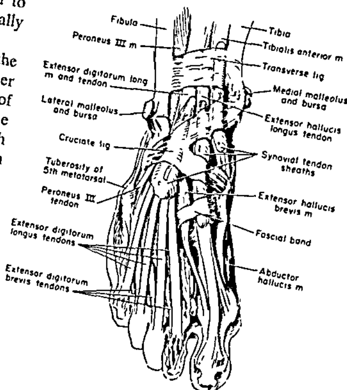


Fig. 3. Muscles and tendons of dorsum of right foot These muscles and tendons lift the foot and the toes. (Howorth, M. Beckett, *et al.*. A Textbook of Orthopedics, Philadelphia, Saunders)

osteoarthritis, but varies much with the relaxed type of club foot.

There is no arch in the ball of the foot, all the metatarsal heads touching the ground and bearing weight about equally except the first, which, being broad, bears about twice the weight of the others. Actually, the sesamoids carry the weight to the first metatarsal head. As the heel rises and more weight goes on the ball of the foot, the longest metatarsal head bears more weight. This may be the first or the second. If the effect is excessive, a callus will develop under the abused metatarsal head. The transverse arch is formed actually by the bases of the metatarsals, or the cuneiforms, the cuboid and the fifth metatarsal; it is incomplete, its inner pillar being the longitudinal arch. This transverse arch does not "fall" unless the longitudinal arch first relaxes. There has been much misunderstanding regarding the transverse arch.

THE INFANT FOOT

The infant is born with little or no arch but with well-developed ligaments, and the bones of the foot, although just beginning to ossify, are well formed in cartilage. He has been exercising the muscles of his feet and legs in utero for several months before birth. He moves the feet and the legs continuously while awake and soon learns to push his feet against the crib or pull them against other resistance, so that he gets resisted exercise. Reciprocal motion, comparable with that of walking, is characteristic of his normal movements. When about 4 months old, he begins to use the feet for turning over, and soon afterward he uses them for balance in sitting and for propulsion. At about 9 months of age he begins to creep or to stand and not only increases the exercise of the feet but also subjects them to the effects of weight-bearing. If the arches and the muscles are developing properly and his legs are straight,

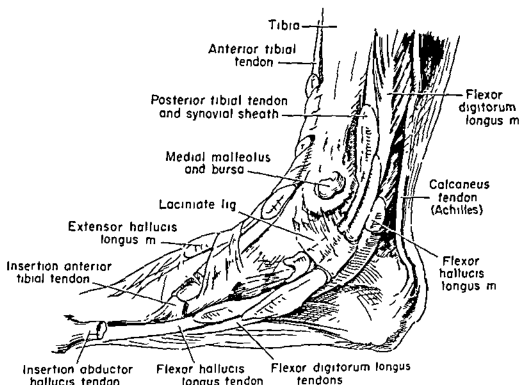


FIG. 4 Tendons of the right foot, medial aspect These tendons invert the foot, whereas the anterior tibial also dorsiflexes the ankle; the posterior tibial and toe flexors plantar-flex it (Howorth, M Beckett, *et al.*, A Textbook of Orthopedics, Philadelphia, Saunders)

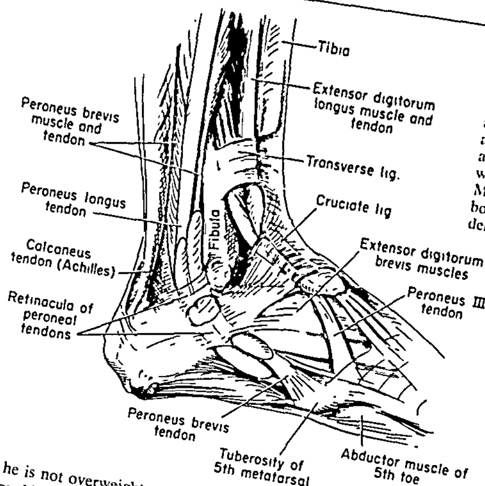


FIG. 5. Tendons of the right foot, lateral aspect. These tendons evert the foot, the peroneus longus and brevis also acting as plantar flexors of the ankle. The toe extensors act as dorsiflexors of the ankle with the toes set. (Howorth, M. Beckett, *et al.*: A Textbook of Orthopedics, Philadelphia, Saunders)

and he is not overweight, weight-bearing for reasonable periods of time will be desirable; however, if the converse is true, weight-bearing will tend to tire the muscles, stretch the ligaments and, in time, even result in some deformity of the bones. At this stage the infant should stand on a firm, flat surface such as a carpeted floor or a firm pad or board in his play pen or crib, particularly if he is heavy or has relaxed arches. He does not need shoes until he begins to spend some time on his feet and then only if the arches are relaxed or he is overweight or needs protection out of doors. Shoes for weight-bearing should have firm leather

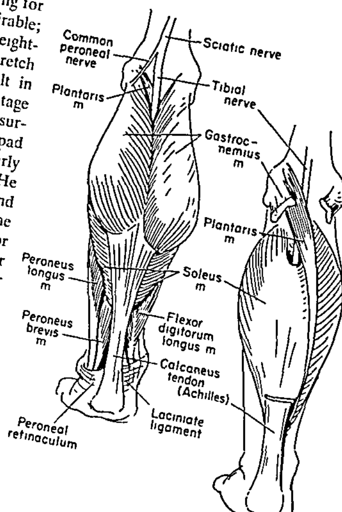


FIG 6 Superficial muscles, posterior aspect of left leg The gastrocnemius and the soleus are the powerful plantar flexors of the ankle, lifting and supporting the entire body weight when rising on the ball of the foot, and much more than the body weight in jumping. The posterior tibial and the peroneals reinforce the action of the calf muscles (Howorth, M Beckett, *et al* A Textbook of Orthopedics, Philadelphia, Saunders)

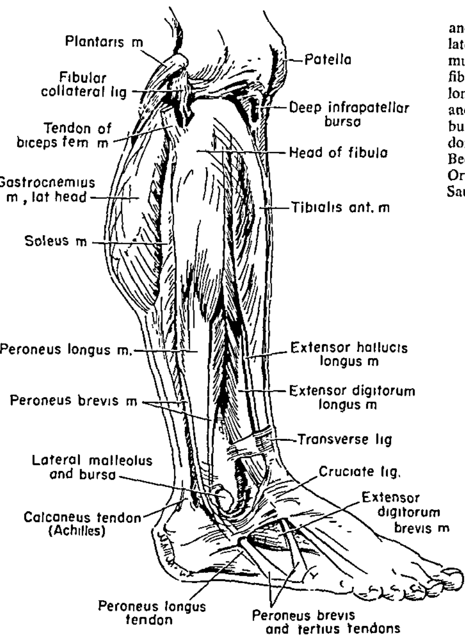


FIG. 7. Superficial muscles and tendons of the right leg, lateral aspect. The peroneal muscles largely surround the fibula ("os peroneus"), the longus and the brevis everting and plantar-flexing the ankle, but the small tertius acts as a dorsiflexor. (Howorth, M. Beckett, *et al.*: A Textbook of Orthopedics, Philadelphia, Saunders)

soles that remain flat transversely, but they should not be rigid, especially at the ball of the foot The uppers usually should be of a strong leather such as calfskin; a high shoe often is preferable at this age because it is less likely to be removed or kicked off and gives a little added protection to weak arches. As the child becomes heavier and more active, the shoe should be more strongly built, with a welt sole

The infant walks alone at about the age of 14 months, but there is considerable variation, depending upon the weight and the agility of the child and the development of the legs. He walks with a wide base, with quick, stamping steps, often almost running. However, he turns poorly, often falls when he tries to turn, and finds even low steps difficult or impossible to climb. At about 2 years, the infant can turn fairly well and negotiate low stairs. During the second year he may be helped by being taught to walk with his feet straight forward and his weight forward on steps or sloping surfaces.

Weak arches may be protected with rubber scaphoid pads in the insteps of the shoes and with wedges in the sole under the instep to level this portion of the sole with

the spring heel. Exercises requiring strong muscle contraction and activities such as pedal-pushing and climbing will help to strengthen the muscles supporting the arch. Babies are born with slightly bowed legs, which gradually reverse in the second or third year and commonly become knock knees. Many babies are born with an internal or an external torsion of the tibias, sometimes of the femurs or the hips, and occasionally there is external torsion of one leg, internal torsion of the other (see Fig. 21). Sometimes the torsional positions, probably secondary to position in utero, are accompanied by contracture of the hip adductor muscles on one side, occasionally of both. Usually, these torsions will become permanent if they are not corrected in infancy. The most important factor in maintaining the torsion is the sleeping position of the infant. Most babies in the United States are trained to sleep prone: in this position the torsion is maintained by the weight on the legs. The torsion can be corrected by the use of a Denis Browne splint, with the legs turned in the opposite position, worn regularly for several months except when the baby is awake and most active. In the meantime the infant can be taught to sleep on his back or his side. Gentle but frequently repeated manual stretchings against the deformity may also be employed. Mild bow legs in a young infant, unless there is an active bone disease such as rickets or scurvy, will correct spontaneously. Knock knees, especially if moderate or marked, are much less likely to spontaneous correction. Knock knees are commonly associated with weak arches, often with poor posture. The treatment of knock knees and weak arches include posture correction, with a firm, flat bed, proper chair, proper shoes with appropriate corrections and exercises for the feet and the legs. If these measures are not successful, by the age of 9 or 10, stapling of the medial femoral epiphyses may be advisable.

The 3 year old has become fairly adept at walking and running and even at jumping and going up and down stairs. The well-co-ordinated 5 year old is proficient in all activities and usually is a good climber.

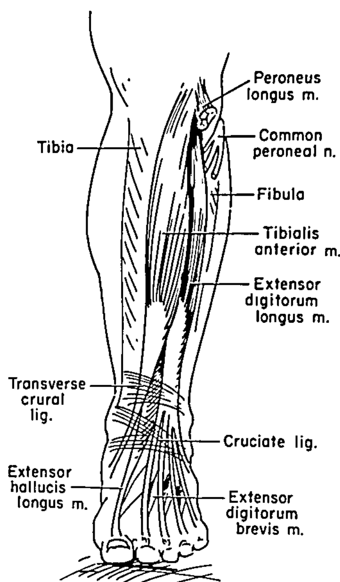


FIG. 8. Superficial muscles, anterior aspect of left leg. The anterior tibial is the powerful dorsiflexor of the ankle, aided by the long toe extensors (and the peroneus tertius). It acts strongly in lifting the foot for jumping and walking upstairs or uphill. (Howorth, M. Beckett, *et al.*: A Textbook of Orthopedics, Philadelphia, Saunders)

STATIC POSTURE

Static posture is inactive posture or posture at rest without anticipated action. It includes the standard positions for lying,

sitting and standing, and the variations of these positions, relaxed or under tension.

The Lying Posture. Lying may be considered the most fundamental human posture, since it usually occupies more hours of the day than any other. However, it has many variations. One may lie on the face or the back; in both cases the position is fundamentally the same, with the body extended and the legs rolled inward or outward, the feet dropped. On the side, the hips and the knees usually are flexed; the spine may also be flexed. The positions of the extremities are changed frequently during sleep, and the body usually is turned at intervals. In any case, the lying position should be one of ease and comfort, permitting complete relaxation. Usually this is achieved more easily on a firm, flat bed rather than a soft, saggy one. Little attention to the posture of the feet is required in lying, except to avoid binding the feet down with the bedclothes.

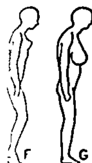
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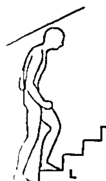


FIG 9 (*Left*) Front of the leg and dorsum of foot, with foot strongly inverted and dorsiflexed The anterior tibial muscle and tendon can be clearly seen throughout its course, the tendon, held down by the transverse and the cruciate ligaments, standing out in front of the ankle medially and passing to its insertion in the medial cuneiform and base of the first metatarsal It can be felt as well as seen (Howorth, M. Beckett, *et al.*: A Textbook of Orthopedics, Philadelphia, Saunders) (*Right*) Lateral aspect of the leg and the foot, with foot strongly dorsiflexed and everted The peroneals are everting the foot, the anterior tibial, toe extensors and peroneus tertius dorsiflexing; the toe extensors, especially the hallucis, extending the metatarsophalangeal joints. The contracting muscles can be seen (and felt) along the fibula.

FIG. 10. Infant weak arches, with marked pronation. The infant is attempting to correct with the right foot by adducting and gripping with the toes. Walking barefoot, or with flimsy shoes, or standing on sagging surfaces, tends to stretch the ligaments and weaken rather than strengthen such feet. (Howorth, M. Beckett, *et al.*: A Textbook of Orthopedics, Philadelphia, Saunders)



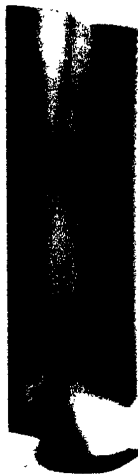




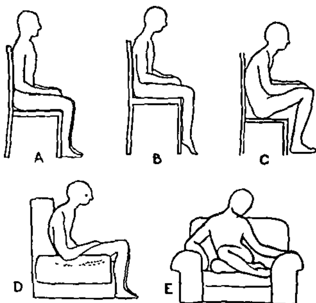
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ture is next in importance to most people because of the large number of hours many of them spend sitting and because of the bad effects of poor sitting posture. The basic sitting position should be with the head and the trunk erect and centered over the pelvis or tilted slightly forward, with a medium or a slight lumbar arch, with the hips, the knees and the feet flexed at a right angle. Like lying, the sitting position is subject to considerable variation, depending both on the person and on the chair in which he sits. The chair should fit the size and the shape of the individual, with a seat depth equal to the length of the thighs, thus giving them good, even support and a height equal to the length of the legs below the knee, so that the feet rest evenly on the floor. A higher chair causes the feet to dangle.

Sitting on the floor or in bed is usually awkward and tiring to those accustomed to sitting in a chair. Sitting with the legs extended is usually uncomfortable because of tension in the hamstring muscles and the tendons in front of the ankle with the feet dropped. Sitting with the legs to one side soon results in discomfort in the foot that is underneath, and sitting with the legs akimbo is soon uncomfortable to both feet. The latter position, however, is probably



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FIGS 12 and 13. Sitting postures. FIG. 12. (A) Erect position, correct chair which fits the lengths of thighs and legs; spine and trunk erect and in balance centered over hips; weight distributed evenly on the entire thigh and sole of the foot. An armchair of this type is even better, as it supports the arms too (B) Chair too high: feet dangle, too much pressure on thighs just above knee; tendency for trunk to slump. (C) Chair too low and shallow: weight concentrated on buttocks may cause coccygodynia; trunk slumped, chest and abdomen compressed. (D) Chair too soft, low and deep: weight on buttocks and sacral region; trunk slumped. (E) Chair too low and deep: legs drawn up beneath thighs, trunk and spine curved and twisted. (Howorth, M. Beckett: J.A.M.A. 131:1398)

most comfortable and least harmful to the posture of the average individual.

The Standing Posture. The standing position may best be thought of as a basic position from which frequent changes are made rather than a position held continuously or rigidly. This basic position has certain ideal characteristics. The feet should be squarely placed, parallel, arches up. The body should be vertical and essentially straight when seen from the side as well as from the back. The vertical line should pass through the ear, shoulder, hip and ankle. The physiologic spinal curves should be slight, the pelvis level and the chest open. The feet and the knees should be directed forward, and the arches should not sag. The body should achieve its full height in this

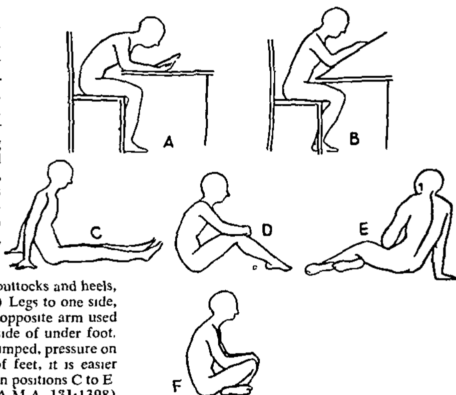
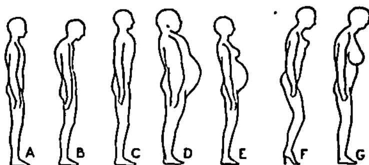


FIG. 13. (A) Ordinary flat desk or table: impossible to sit comfortably erect for reading or writing, trunk badly slumped. (B) Uptilted desk or board. good posture much easier to maintain. (C) Sitting on floor legs extended with hamstrings stretched, pressure on heels, arms usually used as props, tendency for trunk to slump unless hamstrings are long, very difficult to sit erect. (D) Knees and hips flexed, spine slumped, weight on buttocks and heels, dorsiflexors stretched (E) Legs to one side, spine curved and twisted, opposite arm used as prop, weight on outer side of under foot. (F) Legs akimbo, spine slumped, pressure on buttocks and outer side of feet, it is easier to sit in this position than in positions C to E (Howorth, M. Beckett J A M A 131:1398)



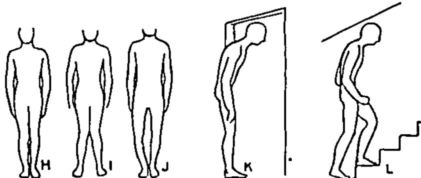


FIG. 14. Standing posture. (A) Erect, good posture, side view: head, shoulder, hip, knee and ankle in good vertical alignment; chest comfortably open, shoulders relaxed, abdomen flat, slight lumbar lordosis; see H. (B) Poor posture, usual type: head and pelvis shifted forward, forming long S curve as viewed from side; thoracic spine stooped, chest flat or sunken, breasts sag, abdomen protrudes, pelvis tilted forward; weight back on heels; the common posture with high heels. (C) Exaggerated erect posture, tense and tiring: head and shoulders forced back, chest raised forcibly, abdomen "sucked in," arms and legs rigid, circulation slowed. (D) Posture of obese person: abdomen large and protruding, throwing body out of balance forward, compensated by sway back, forming long C curve of trunk as seen from side; increased strain on lumbar spine. (E) Posture of pregnancy, similar to obesity, but more transient. (F) Posture of high heels, second type: hips and knees flexed, lumbar lordosis increased, buttocks protruding; first type similar to B. (G) Large breasts pull upper thoracic spine, head and neck forward, flatten chest.
(H) Erect posture, front view: legs straight; see A. (I) Posture of knock knees, feet pronated also. (J) Posture of bowlegs, feet pronated for compensation. (K) Poor posture caused by low doorway. (L) Poor posture caused by low stairway. (Howorth, M. Beckett: J.A.M.A. 131:1398)

position, with a feeling of tallness, the top of the head pulling away from the soles of the feet.

The weight should be slightly more on the heels, although with expected forward movement the weight should shift toward the balls of the feet. Shifting the weight backward or forward alters the reflex effect on the muscles, and for simple standing the best reflex muscle tones are attained in the former position, whereas for anticipated forward movement the tones are better with the weight forward. Better lateral balance is secured by separating the feet and the legs sideward. With the feet together the adductor muscles are relaxed and the abductors are active When the feet are separated farther than the hips, the adductor muscles become active, and the abductors relax. Similarly, with the feet together the peroneals are more active, and with the feet separated activity shifts toward the tibial muscles. Fore and aft balance is better with one foot advanced; with the heel down this tends to stretch the calf of the rear leg, the anterior tibial muscle of the leg in front.

The basic standing position is varied constantly during standing for comfort and for purposeful movements. The weight may be shifted toward one leg or the other, or backward or forward, allowing stretched or tense muscles or ligaments to relax. The body in motion tires less easily than the tense and rigid body. Good posture should be comfortable, without effort or tension. It is a matter of learning to control the positions of the body and to bring its various parts into line and balance without tension or rigidity.

Certain individuals are tense, with overactive (hypertonic) muscles, causing abnor-

mal pulls by the stronger and more tense muscles, affecting not only posture but also performance. Others are "muscle bound" with short, strong muscles and ligaments that cannot be fully stretched out, also affecting posture and performance. Still others are "relaxed" because of hypotonic muscles and elongated ligaments with joints that extend too far. Weak arches and knock knees are a common manifestation of such relaxation.

POOR POSTURE

Poor standing posture is characterized by a forward movement and tilt of the pelvis, with an increased lumbar lordosis, thoracic round back and flat chest. The knees flex, the abdomen sags and protrudes, the chest flattens, and the shoulders, head and neck are advanced. The height is diminished, and the body as seen from the side forms a long S curve. It is as though man, having attained the erect position, is now trying to continue backward until he reaches a reverse position on all fours. The feet are directed outward, but pronated, and the arches are relaxed. This is the position so valiantly strived for in recent years by fashion photographers and models, nearly all alike, except that the girls always pose with their mouths open as though trying to catch something!

Causes of Poor Posture. Certain factors tend to prevent good posture: fatigue, lack of sleep, emotional depression, malnutrition, laziness The corpulent abdomen throws the body off balance, the upper part of the trunk is thrown back to maintain balance, resulting in a sway-back posture and back strain. Late pregnancy tends to produce the same effect, but the effect is short lived (see Fig. 14). The self-conscious tall person may assume poor posture to reduce his height or to avoid striking his head against low doorways or stairways High heels tend to throw the weight forward, this effect may be counterbalanced by swaying the back into a position of poor posture, or by flexing the knees and the hips, throwing back the buttocks. Either of these positions is be uncomfortable and fatiguing as w unsightly. With high heels, which ar narrow and closer to the balls of th balance is poor, the peroneal and the muscles work overtime, the anterior ti stretched, and the calf muscle graduall tracts and shortens. A contracted calf to increase any tendency to weak a There are various other unhappy effe high-heeled shoes.

Effects of Poor Posture. Poor p is assumed because it is the easiest and natural position of the person at the m he assumes it, and it provides relaxatio rest for certain muscles and for the bo a whole. It is basically a "letting g response to the effects of gravity. continuous or habitual poor posture t really harmful. Bad posture overstre some of the muscles and ligaments, r others and allows the stronger or the sh ones to contract further, increasing th effect. Poor posture reduces the circul locally and generally, diminishing the m olism and the efficiency of the cells an tissues, inducing drowsiness and slug ness. The physical and emotional attitu one of depression. Backache, leg and pain are frequent symptoms of poor pos

Posture Correction. The starting for posture correction is usually with th and shoes. It is impossible to have body posture with poor foot posture poor shoes. The first step is to acqu pair of strongly built, well-fitted oxfor a proper foundation for the weight o body. This is even more important i arches are weak or the person is heavy very active on his feet Scaphoid pad wedges are added if advisable. Next, individual is taught to stand with feet sq directed forward, and arches up to a no position. This should become his new h True arch strengthening exercises are g and followed diligently. Unless there structural deformity of the spine, the re easy. The pelvis is brought back into

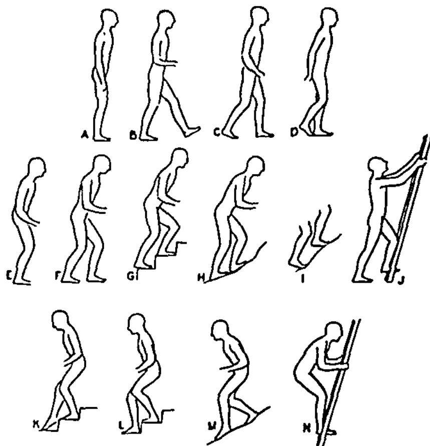


FIG. 15. Dynamic posture. (A) Basic dynamic position for walking: slight crouch, slight flexion of hips, knees and ankles, with trunk tilted forward slightly. (B) Walking, first phase: advancing leg extended, opposite arm flexed. (C) Walking, second phase: weight shifting to forward foot, rear knee slightly flexed, leg swinging forward. (D) Walking, third phase: rear leg reaching extended front leg, arm swinging back.

(E) Basic dynamic position, crouch increased for walking rapidly or on slippery surface, or up or down hill. (F) Same, walking rapidly or on slippery surface. (G) Same, walking upstairs: weight mainly on forward leg (H) Same, walking uphill: heels down, reducing effort for calf, but increasing effort for quadriceps muscle; impossible with contracted calf. (I) Same, walking uphill: heels up, reducing effort for quadriceps but increasing effort for calf muscle as well as tendency to slip back. (J) Climbing ladder: arms above shoulders, weight shifting to upper leg, hips and trunk well back for better vision and weight thrust; see N.

(K) Walking down steps, first phase, moderate crouch, weight forward, one foot descending to step below, upper foot occupying whole step. (L) Walking down steps, second phase: same, but weight going on front leg on lower step; safest and most flexible position. (M) Walking downhill: moderate crouch, weight forward, entire sole on ground, reducing tendency to slip. (N) Descending ladder: position of dynamic posture; hands move down first, then trunk, finally foot; hips, trunk and head well back for better vision, weight thrust and balance. (Howorth, M. Beckett: J.A.M.A. 131:1398)

with the ankles and the shoulders, the chest opened, the head and the neck stretched upward to full height, the lumbar spine flattened. The subject should have a proper bed and chair. It may also be necessary to correct faulty hygiene or nutrition, lack of sleep and other causes of fatigue. Exercises for the trunk muscles, including the stretching of contracted muscles and the strengthening of those relaxed, such as sagging abdominals, are of great importance. Appropriate sports are fitted into the program. Often the psychological care of the patient is as important as the physical. Posture consciousness must become an important part of his life until correct habits are acquired.

DYNAMIC POSTURE

Definitions and Basic Principles. Dynamic posture is posture in motion or in action or in preparation for action. It includes the transitions between the static positions of lying, sitting and standing and such activities as walking, running, jumping, climbing, pushing, lifting, dancing, swimming, work and play. Dynamic posture includes the uses of the upper extremities and the trunk as well as the legs and the feet, and the relationships between the various parts of the body in action. The feet play an important part in many of these activities. The common denominators of

dynamic posture are essentially the same whatever the activity. Dynamic posture should not be limited to specific sports or activities but should be understood and applied to all our activities throughout our lives.

Good dynamic posture implies the use of the body or its parts in the simplest and the most effective way, using muscle contraction and relaxation, balance, co-ordination, rhythm and timing, as well as gravity, inertia and momentum to maximum advantage. The smooth integration of these elements of good dynamic posture results in neuromusculoskeletal performance that is easy, graceful, satisfying and effective, and represents the best in the individual physical activity as well as the physical activity of the individual.

Gravity pulls the body or its parts toward the earth. Inertia tends to hold the body still or to maintain its motions at a constant speed, while momentum gives the body added power or impetus. Friction, including air resistance, tends to slow the body; friction is particularly applicable to the feet. Gravity, inertia, momentum or friction may be overcome or reinforced by muscle action. Acceleration or deceleration may be caused by an external force, such as gravity or friction, or by the internal force of muscle action.

A muscle may contract or relax, in whole or in part. A contracting muscle may work against gravity by lifting; it may aid gravity by pulling downward. A muscle may relax and thus by letting go allow gravity to become more or less effective. Similarly, inertia, momentum or friction may be resisted or reinforced by the proper application of muscle contraction or relaxation. Maximum power is attained by the contraction of the muscle in the most favorable relation to gravity, inertia and momentum, with a minimum of friction The contraction need not be sustained but should be continued just long enough to produce the desired effect Thus, tension and fatigue are avoided, and the muscle is free to perform further work.

Good balance is secured by maintaining the center of gravity of the body over the feet through co-ordination of the eyes, the semicircular canals and the position sense of the muscles and the joints. When the body is moving forward, the center of gravity should be advanced to the balls of the feet or in front of the feet so that gravity will provide forward momentum. The trunk should lead the action rather than try to catch up with it.

Precision and smoothness are essential to good muscle action and low energy output. Timing is one of the most important and delicate phases of movement, especially of a complex one. Poor timing can reduce or invalidate the effectiveness of movement. Good timing makes the movement easier and more effective. Alternating contraction and relaxation with balanced timing produce rhythm in movement and increase the capacity for repeated actions. Co-ordination is the smooth relationship in proper sequence of a group of muscle actions. Precision, smoothness, timing, rhythm and co-ordination are the elements of good dynamic posture. All these principles apply to the feet as well as to other parts of the body.

The Basic Dynamic Position. The basic dynamic position is characterized by a slight crouch, with the ankles, the knees and the hips flexed, the trunk inclined forward and slightly flexed, the arms relaxed and slightly flexed. With the body in this position the muscles are in mid-position with increased tone, balanced and ready for instant and powerful action in any direction. They act also as springs, absorbing shocks and initiating movement. This basic position is assumed in many sports, such as football, track, tennis and skiing. Fore and aft stability is increased by advancing one foot, whereas lateral stability is increased by separating the feet sideways. Thus, the feet secure a firmer grip on the ground than in the erect position, preventing slipping and increasing the thrust forward movement. Basic dynamic posture is quite different from poor posture.

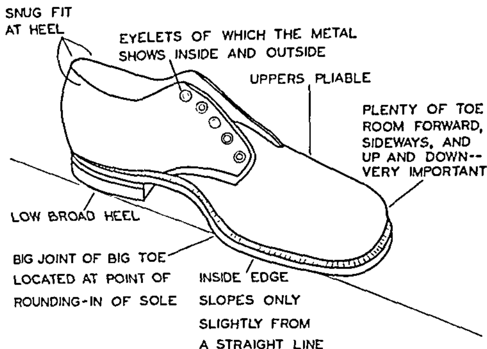


FIG. 16. Shoe, desirable features for adults as well as children. (Howorth, M. Beckett: Consumers' Research Bulletin, May, 1943)

WALKING

Walking is one of our simplest and most fundamental actions and is an excellent example of dynamic posture. The body should be tilted slightly forward from the basic standing position and the weight thrown on the ball of one foot, while the opposite thigh is lifted and the leg swung forward. There should be a feeling of forward falling, requiring that the weight be caught on the advancing foot. Various muscles, aided by inertia, maintain the body in balance on the ball of one foot until the opposite heel or foot strikes, when the weight quickly advances to this leg with the knee extended. Momentum carries the body forward over the extended leg until it passes the perpendicular, when the thrust of the foot renews the action and the process is repeated (see Fig. 15).

The quadriceps muscle contracts for only a fraction of a second, with a sort of rippling movement in swinging the leg forward. The muscles in front of the ankle contract briefly to prevent the foot from dragging just as it swings across the ground.

As the heel strikes, all the thigh and the ankle muscles quickly contract to stabilize the knee and the ankle until the weight is thrust forward again by the calf. The flexor muscles in front of the hip swing the thigh forward. Then, as the weight goes on the leg, all the hip muscles contract to stabilize the hip, particularly the abductors, to prevent the pelvis from falling to the inner side. The opposite arm swings forward with the leg by contraction of the shoulder and the elbow flexors, then swings back by the action of their antagonists. These motions are greatly aided by the pendulum effect of the swing.

Correct walking is done with a smooth rhythm, the muscles contracting gently with a brief wavelike action and relaxing in the interval. It is characterized by free muscle and joint action, momentum, balance and rhythm. Effort becomes much greater if the speed is increased or if the momentum and the rhythm are disturbed.

Walking is often done badly, with the body erect and stiff, with sudden jerky movements, tense muscles, precarious balance, needless jolts and a lack of rhythm. The steps lack spring and the flexibility needed to meet unusual situations The good walker should be able to change pace, stop, start, turn, step up or down, twist or stoop, easily and quickly, without losing balance or rhythm. A good dynamic posture and flexi-

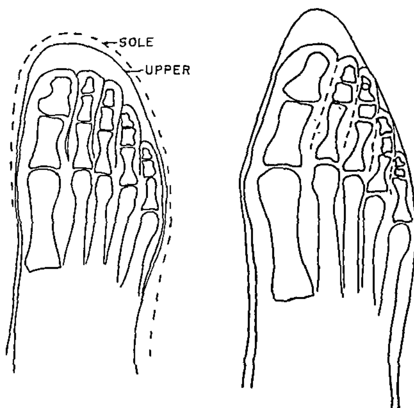


FIG. 17. (*Left*) Tracing f roentgenogram of average in broad-toe shoe (Munson la Toes lie straight without cro ing, leaving room for movem ventilation and circulation. S is of proper length and wi Shoes for young children usu have these characteristics, few shoes for adults do. (*Rig* Tracing from roentgenogram average foot in common t of adult shoe. Note crowding toes, with overlapping, inter ence with circulation, press on small bones of toes caus soft corns, pressure of box of causing hard corns, angulat

ers' Research Bulletin, M. 1943)

ble healthy muscles are the basis for correct walking.

Shoes should be comfortable and of proper shape and fit. High heels and pointed toes or loose, flimsy shoes prevent good walking. Crowded city pavements and dirty, fume-laden air usually promote bad walking posture; the varied topography and surfaces and the clean air of the country make good walking posture more natural

Speed may be acquired by increasing the crouch and the forward tilt, thrusting harder with the feet and developing a stronger arm swing. The length of stride should not be too great, as the effort in forcing the body to reach the forward leg would become excessive, or too short, for energy is wasted in swinging the legs too many times The same principles apply in running.

CLIMBING

Walking uphill or upstairs may be made easier, safer and faster by leaning forward in a deeper crouch and forcing the body well forward on the higher step. Breathi should be deeper rather than faster and rhythm with the other movements. The should be no tenseness of the muscles, f this results in quick fatigue Nor shou there by any disturbance in rhythm smoothness, as one would quickly lose rath than gain in accomplishment.

Walking downhill also requires a forwa lean and slight crouch to reduce the shoc of each step as well as the chance of sli ping In this position the center of gravit is low, and the muscles are in position t respond to any need. The weight come down on the whole foot, the whole step i used, and the foot grips well. Thus, one ca double up and protect one's self much easie in case of a fall. On very steep slopes slight turning to the side or zigzagging wi help. Relaxation is most important in down hill walking, especially "loose knees." Th movement then becomes almost a dance with light, quick steps, or a series of slides, similar to skiing. Small jumps may ofter

be used. The knees usually are kept close together in this technic. The crouch brings one closer to the ground, with the muscles and the joints acting as springs, minimizing the possibility and the danger of a fall. Most falls are backward, with the body extended in a blind direction, the weight coming hard on the coccyx or the wrists. These falls can be avoided by the method described.

The pace is varied according to the difficulty of the terrain, the capacity of the walker and the need for hurry. Most walkers do better if they adopt an easy pace; thus they can maintain rhythm and relaxation. Speed is adapted to varying conditions, so that the energy output is fairly constant. Sometimes it is better on certain types of terrain to rush a short bit, especially with a heavy load, as considerable energy may be wasted in forcing one's self slowly up or down. Similarly, in the face of a strong wind, especially if it is laden with snow or sleet, one may advance by quick rushes. A rest period of 5 minutes every hour is usually desirable, especially if the climbing is difficult or the load is heavy.

Normally, the whole foot should be placed on the ground. Walking on the toes reduces the strain on the quadriceps muscles but increases that on the calves and on the ankles. Toe walking is suitable for short distances steeply uphill or on stairs, but usually it is better to turn the feet to the side, together or crisscross, and use the whole foot. Proper placement of the foot is important, so that it will be as nearly horizontal as possible, on a solid surface, one which is not slippery.

The security of the foot may be increased on a hillside by increasing the area of contact, pushing into the surface perpendicularly or pushing the side of the foot against an adjacent surface. On a rounded surface the instep may be more secure than the ball of the foot; the heel usually is less secure. The hands may be used for balance, or even for assistance, but, normally, the bulk of the work should be done by the legs. Facing out is usually best in climbing down, but in difficult climbing it may be preferable to face sideways or even inward, as in climbing a ladder.

EFFECTS OF ABNORMALITIES OF THE FEET AND THE LEGS

Weak arches relax and pronate on weight-bearing, leading to easy fatigue and even aches and pains in the feet and the legs. The individual with weak arches usually toes out in walking, with a mechanically ineffective gait, the body moving forward while one foot is directed to one side, the other foot to the other side. Thus the strength of the push-off from each foot is diminished, while the strain on the arch and the tibial muscles as well as the inner side of the knee is increased. Weak arches are frequently associated with knock knees, sometimes with external torsion of the tibias, and the effect in walking is for each element of the deformity to aggravate the other. With knock knees the tendency is for the feet to be separated further sideways on walking, increasing the strain on the inner side of the feet and the legs, or for the knees to slide around each other, either tendency being mechanically poor for walking. These effects are aggravated in high-heeled shoes. Weak arches and knock knees tend to promote, or are often associated with, poor body posture, each aggravating the other. All too often obesity becomes another serious factor. Treatment, then, must be directed at all these factors—each of which, fortunately, can be improved or corrected—before much can be accomplished with the gait or the performance of the feet and the legs.

High arches have a very different effect. In standing the weight is concentrated on the heels and the balls of the feet, with a tendency to calluses in these regions. The calluses may become painful, especially in the balls of the feet, and the pain will affect the gait. The gait loses lift and strength

because of the partial rigidity of the foot and, therefore, loses speed and power. This effect is aggravated by high heels, and high arches are apt to become worse with high heels.

A short leg, if not too short, is usually compensated for in standing by dropping the pelvis on the affected side. If there is much shortening, the knee is flexed on the long side, or the foot of the short leg is placed in the equinus position. This results in a tendency to callus under the ball of the foot. Otherwise, compensation may be achieved with a built-up shoe. In walking with a short leg, the body dips down on the short side; there is little or no sway to that side. Ordinarily, a child with a slightly or a moderately short leg, without other deformity or restriction, has little or no handicap in walking, in running or at play.

Bow legs usually do not interfere with the mechanics of walking unless the deformity is severe; in that case the knees are off center and off balance, the feet pronate to compensate and to remain straight on the ground, and the gait is disturbed correspondingly. Bow legs of such degree should be corrected, especially in a child.

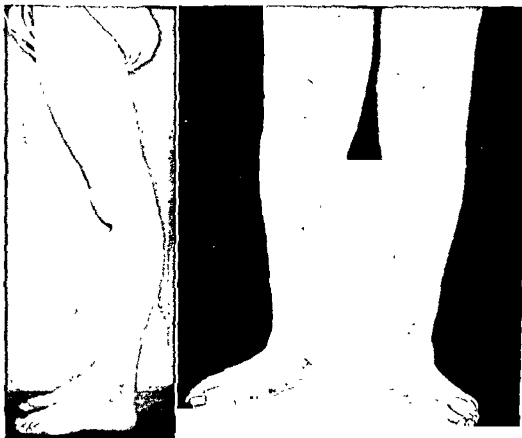


FIG. 18. (*Left*) Recurvatum of knees. The knees hyperextend to 210°, due to stretching or relaxation of the posterior capsule and elongation of the hamstrings This might be seen with general relaxation of the ligaments, or after paralysis of the hamstring muscles. If the Achilles tendon is contracted, the effect is increased Standing posture and gait are affected adversely. (*Right*) Pronation, extreme degree The heels are in valgus, but the foot is swung further out in relation to the talus, and the arch is completely flat. The ankles are almost in line with the knees, but the feet are turned far out. Knock-knee is the common accompaniment of weak arches, and both these deformities are commonly associated with generally relaxed ligaments and poor body posture. Foot posture and gait are affected adversely. (Howorth, M. Beckett, *et al.*: A Textbook of Orthopedics, Philadelphia, Saunders)

Internal torsion of the tibias or the femurs causes an intoeing gait, with a tendency to roll over the outer border of the foot and the shoe, and, if marked, painful calluses may develop under the fifth metatarsal. External torsion is associated with pronation and often with knock knees, and the foot tends to roll over its inner side in walking, with corresponding distortion of the shoe. Calluses may develop on the inner side of the foot, especially at the navicular or along the great toe, sometimes becoming painful. The effectiveness of the gait is diminished by any type of torsion. Sometimes there is internal torsion of the femurs, external torsion of the tibias, which may compensate partially at least for each other in deformity, less so in mechanical performance. Sometimes the hamstring tendons and the knee-joint capsule posteriorly are so relaxed that the knee hyperextends, even as much as 20 or 30°. This may or may not be associated with a contracted calf or an Achilles tendon and is aggravated by such a contracture (see Fig. 18). Standing with the knees relaxed, the posterior structures of the knee are further stretched; in walking, especially if there is weakness of the hamstrings, the knee is thrown into recurvatum, causing undue fatigue of the flexor muscles, further stretching of the capsule and a peculiar and poor gait.

Foot disorders such as corns and calluses, plantar warts, especially those in the balls of the feet, and bunions tend to disturb gait because of pain. Hallux valgus is often associated with and related to pronation. Foot deformities, such as equinovarus club foot, disturb the gait mechanically, sometimes with pain as well. The varus foot tends to roll over its outer border, the equinus foot to have too much weight on the ball of the foot. The arthritic rigid flat foot, usually in some valgus, loses push and flexibility, often aggravated by pain.

RUNNING

Running is much like faster and faster walking, but there is much more movement in the ankle, a more vigorous thrust from the ball of the foot, landing on the ball of the foot instead of the heel, more up-and-

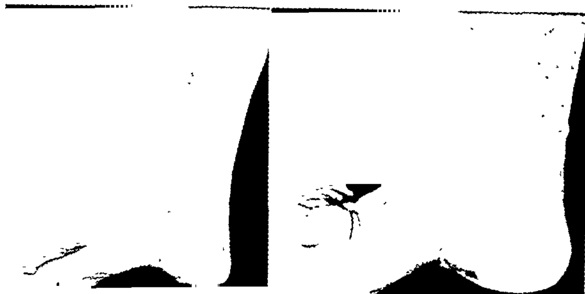


Fig 19. Pes cavus or high arch, seen with poliomyelitis or Friedreich's ataxia. The plantar fascia is contracted. Weight is concentrated on the heel and the ball of the foot, tending to formation of painful calluses. (*Left*) Toes straight. (*Right*) Toes cocked up, with contracture of toe extensor tendons and capsules (claw foot). The deformity is aggravated by high-heeled shoes. (Howorth, M. Beckett, *et al.*: A Textbook of Orthopedics, Philadelphia, Saunders)

down movement of the body, more action in the legs and the arms, and deeper breathing. *Distance running requires an easy rhythm* that can be maintained with a minimum of energy and yet a maximum of speed over a given distance. Deep and well-synchronized breathing is essential for the maintenance of prolonged vigorous muscle action. Proper pacing and allowance for the final effort at the finish is important in racing. The shorter *distance sprinter tends to exert maximum* effort from beginning to end, without changing pace or style. Irregular or up and down hill terrain requires greater flexibility in the use of the feet and the legs in order to maintain speed and balance without sacrificing



Fig 20. Effect of short leg. (*Left*) Correction by dropping pelvis on short side, especially if there is little shortening. (*Right*) Correction by placing foot in equinus position, weight concentrated on ball of foot, *with tendency to painful calluses The short leg causes a limp, with* dipping down on the short side, unless compensated by a built-up shoe. (Howorth, M Beckett, *et al.*: A Textbook of Orthopedics, Philadelphia, Saunders)

energy. Running in ball games requires great flexibility of pace, direction and speed for the exigencies of the game, calling for more vigorous and varied use of all the muscles of the legs and the arms.

As the weight goes on the ball of the foot in such activities as running and jumping, the hip and the knee flex, the hip extensors and the quadriceps contract strongly, but the ankle remains near 90°. The body weight is supported by a strong contraction of the calf muscle, aided by the peroneals, the posterior tibial and the toe flexors, while lateral balance is maintained by the tibials and the peroneals. The ankle plantar flexes with the push-off and dorsiflexes on landing, these same muscles supplying the needed power, balance and spring.

JUMPING

Jumping has many varieties and purposes. It may originate from a standing, stepping or running start, with a take-off from one or both feet, landing on either or both feet. Its object may be to cover distance, to obtain height or to clear an obstacle. A jump from one foot and landing on the other is commonly called a leap; landing on the same foot, a hop; two successive small jumps from the same foot, a skip; and [illegible]-

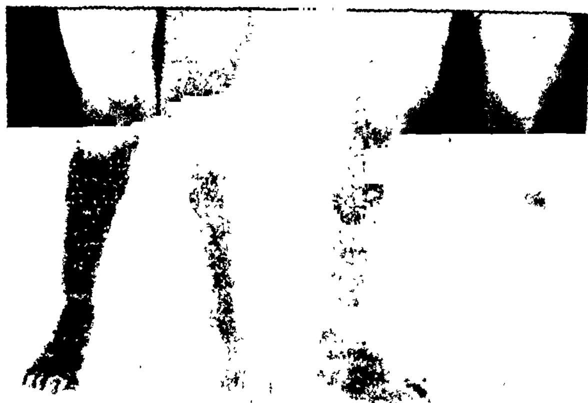






FIG. 22. Hammer toe (*Left*) Congenital fifth hammer toe with large callus. In infancy the toe can sometimes be corrected by persistent stretching. At this stage the toe is useless and surgical correction is difficult, but removal of the toe relieves the symptoms (*Right*) Second hammer toe, congenital or acquired, often because this is the longest toe and the shoe is too short. May be corrected by wedge resection and arthrodesis of the interphalangeal joint. Removal undesirable, as great toe then swings into valgus. Such deformities affect gait chiefly by causing pain when ordinary shoes are worn (Howorth, M. Beckett, *et al.*: A Textbook of Orthopedics, Philadelphia, Saunders)

times there are combinations of these. The usual jump is a leap, springing from one foot and landing on the other, with a standing, stepping or running start and a stepping or running finish. The leap may be broad, to clear a wide space, or high, to clear an obstacle or to rise to a higher position. When the forward motion is to be continued



FIG. 23 Plantar wart under first metatarsal head, surrounded by callus. Such warts, especially when under a metatarsal head—a common location—are apt to be very tender and painful on weight-bearing, thus affecting gait. (Howorth, M Beckett, *et al.* A Textbook of Orthopedics, Philadelphia, Saunders)

FIG 24 (*on facing page*) Hallux valgus. (*Top, left*) Hallux valgus with medially prominent first metatarsal head, or exostosis Great toe rotated internally, nail diseased Third hammer toe, marked. Moderate pronation (*Top, right*) Moderate hallux valgus with second toe overlapping; moderate exostosis, moderate pronation (*Bottom, left*) Marked hallux valgus, great toe rotated (*Continued on facing page*)



FIG 24 (*Continued from facing page*)
internally; hammer toes with second toe overlapping the first. Many corns and calluses. This type of deformity is seen with rheumatoid arthritis; it is difficult to correct, even with surgery. (*Bottom, right*) Marked hallux valgus with internal rotation of great toe, overlapping the second toe. Exostosis is small. Arch good, slight pronation. Pronation often accompanies hallux valgus, and each aggravates the other, adversely affecting gait. (Howorth, M. Beckett, *et al.*, A Textbook of Orthopedics, Philadelphia, Saunders)

on landing, the feet are used successively, as in running, and the weight is kept forward. When the landing is stationary or uncertain, or after a downward leap, the landing is often made on both feet simultaneously, with one foot slightly ahead for greater stability and the weight slightly back for stopping. Jumping from both feet is possible, but more difficult, because there is less spring and momentum, although the initial footing is more secure. The arms aid in lifting the body by leading the movement from the crouch position, followed by the trunk and, finally, the rear leg. Precise timing is most important. There is a strong contraction of the plantar muscles of the foot at the moment of take-off, and these muscles act as springs at the moment of landing.

An obstacle may be jumped, hurdled or vaulted, depending upon its size and stability and the capacity of the jumper. In hurdling, the legs usually are drawn up and to one side. Vaulting may be done with one hand and arm on, and directly over, the obstacle for balance and support, with a sideward turn resulting in an about-face of the body. In case of doubt it is safer to climb rather



FIG 25 Equinovarus rocker foot The heel of the right foot does not reach the floor, and the foot is bent in the middle (mid-tarsal joints), resulting in forefoot adduction as well as a rocker deformity; the arch is high. Weight is borne largely on the fifth metatarsal, where a callus tends to form, often painful The head of the talus projects toward the lateral side of the foot in front of the ankle This type of deformity may be seen with congenital clubfoot, sometimes following poliomyelitis, or with cerebral palsy. In walking, the *foot tends to roll over its outer border,* also deforming the shoe. The left foot is pronated slightly, the leg is slightly bowed. (Howorth, M Beckett, *et al.*. A Textbook of Orthopedics, Philadelphia, Saunders)

than to jump, or to go around an obstacle, particularly if there is a definite hazard below or on the other side.

OTHER APPLICATIONS

The basic dynamic position is an excellent one for many of the activities of everyday life. It may be used in various ways in the transitions from the lying to the sitting and the standing positions. Rising from a chair is easier and more graceful when one or both feet are moved back, under or beside the chair, and the trunk is tilted forward. The movements may be reversed in sitting down. Steps and curbs are ascended and descended much more easily and safely in this position. Heavy doors can be pushed open or shut from this position with less effort and better protection. Lifting, especially if it is done with the aid of momentum, is much easier and safer. The weight should be close to the body, with the trunk erect and the lifting done with the legs. Falls on slippery surfaces, waxed and slippery floors and steps are nearly always backward and often result in fractures of the wrist, spine, coccyx or ankle. In falling backward one cannot see where one is going or double up to protect one's self. It is almost impossible to slip on a slippery surface in the crouch position because the feet grip much more firmly. Falls from this position are forward, where one can see and double up for protection.

The basic dynamic position is often used in sports and is well known to coaches and athletes. The track runner, jumper, football or basketball player, tennis player, horseback rider, boxer and skier use it regularly, and it is frequently assumed by the gymnast and the dancer and in the course of the various ball games. In these various activities the footwork is often intricate and skillful and very important to the proper handling of the rest of the body.

Good dynamic posture may also be used by the housewife, the industrial or farm worker and even by the surgeon and the nurse. It is a method of action in which inertia, momentum, power, balance, rhythm

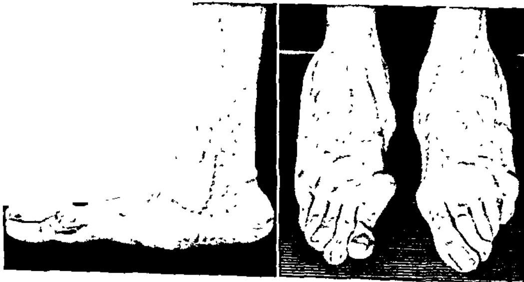


FIG. 26. Completely flat feet, with moderate pronation, arthritic, almost rigid Osteoarthritis of great toe joint with hallux valgus and no extension, hyperextension of interphalangeal joint. Large dorsal adventitious bursa on the right. The gait with such feet lacks power and spring, and walking is often painful. (Howorth, M. Beckett, *et al.*: A Textbook of Orthopedics, Philadelphia, Saunders)

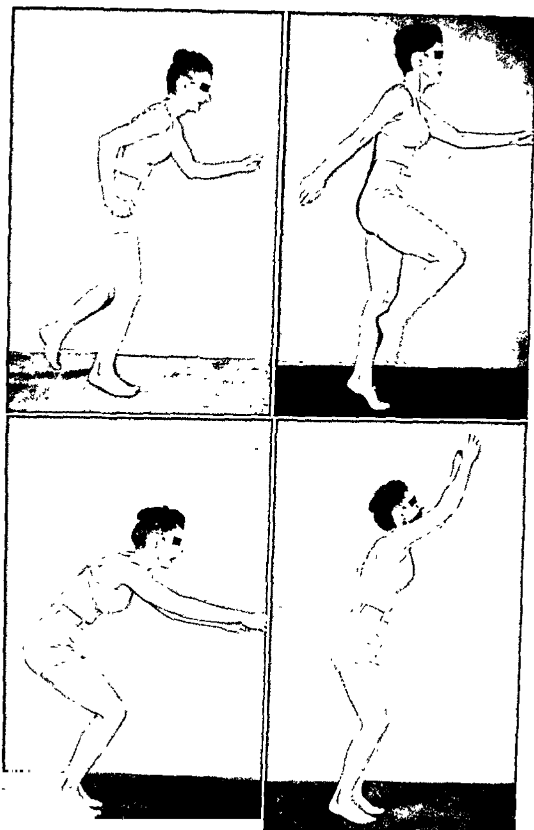


FIG 27 Dynamic posture in running and jumping. (*Top, left*) Running: basic dynamic position with moderate crouch, weight forward on ball of foot, supported by strong contraction of calf and accessory muscles, quadriceps and hip extensors Weight is thrust forward from the ball of the foot for the advancing opposite leg and foot, arms swung more forcibly, breathing deeper Balance of foot maintained by tibials and peroneals (*Top, right*) Skipping position and mechanics similar to those of running, except that two quick jumps are made from the same foot each time, while the opposite leg is held momentarily suspended in the flexed position

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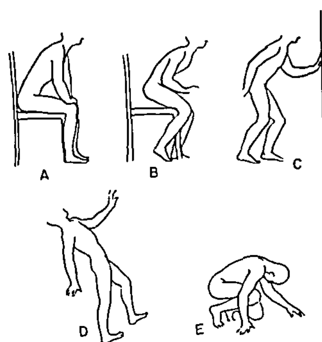


FIG. 28. Dynamic posture. (A) Rising from chair, usual way: weight back of heels, requiring strong thrust with hands against chair or thighs that calls for much effort and off balance. (B) Rising from chair, good dynamic posture: feet back, shoulders forward, moderate crouch, balance over feet, little effort. (C) Opening heavy door or pushing furniture, basic dynamic position: weight forward, elbows flexed, little effort as the weight of the body assists the effort. (D) Falling, usual way: weight back on heels which slip out from under body; body falls back, subject cannot see behind or double up to protect himself, falls on outstretched arm and breaks wrist, or on buttocks, injuring coccyx or spine. (E) Falling, correct way: good dynamic position, weight forward, body doubles up and rolls to minimize and cushion fall; subject can see as he falls forward (Howorth, M. Beckett. J.A.M.A. 131:1398)

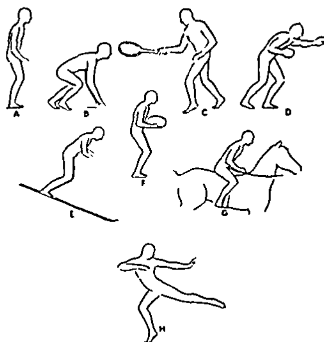


FIG. 29. Dynamic posture. (A) Basic dynamic position: moderate crouch. (B) Crouch and forward lean, as used for quick forceful start by track runner or football player. (C) Tennis player: stroking in basic dynamic position, left leg advanced, weight forward, the whole body participating in the swing. (D) Boxer: basic dynamic position with forward lean and thrust with whole body as well as arm. (E) Skier: basic dynamic posture with moderate crouch and forward lean, whole body participating in movements for making turns. (F) Weight-lifting: basic dynamic position, arms and weight close to body, lifting done mainly by knee action instead of straightening spine. (G) Horseback rider: basic dynamic position, moderate crouch; crouch intensified for high-speed riding and jumping. (H) Dancer: basic dynamic position, with weight centered over one leg. (Howorth, M. Beckett: J.A.M.A. 131:1398)

FIG 27 (*Continued from facing page*)

(*Bottom, left*) Jumping, standing start from both feet: moderate or low crouch, weight forward, arms swung forcibly forward almost extended, weight and balance as in running but on both feet. (*Bottom, right*) Jumping for height: as at *bottom, left*, but the arms are swung forcibly upward as body is extended from crouch, then the legs are brought up toward the hips (Howorth, M Beckett, *et al.*: A Textbook of Orthopedics, Philadelphia, Saunders)

and co-ordination reach their optimum development.

CONCLUSION

Movement is the basis of dynamic posture. Good dynamic posture is natural to such animals as the cat and the horse, is common in primitive man and often in children, much less common in adult civilized man. Usually it is not acquired easily and instinctively but requires effort and training, especially when applied to all one's activities. The feet play an essential and most important part in good dynamic posture.

Good dynamic posture frees the individual from tension and gives the body a feeling of lightness, of moving through space, rather than being earthbound. The body then becomes the instrument of the individual rather than the anchor dragging at the day's activities. The tendency to fatigue is reduced, and there is more energy left for other things. Accidents are far less common and usually less serious with good dynamic posture. The principles of good dynamic posture, precision, smoothness, power, balance, good timing, rhythm and co-ordination may be used not only for the physical body in action but also as an approach to life itself.

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Dynamica Postural e le Pede

Summario in Interlingua

Postura static e postura dynamic es definite e distinguite. Le anatomia del pede es summarisate brevemente con respecto a su rolo in le postura static e dynamic. Le disveloppamento e le uso del pede infantil es delineate. Le posturas static in jacer, seder, e star es describite. Mal habitudes postural, lor causas, effectos, e correction es discutite.

Postura dynamic es postura in action o preparation al action. Le denominatores commun de omne formas de bon postura dynamic es applicabile a multe diurne activitates, occupationes, e sports. Postura dynamic es relationate al fortias externe de gravitate, inertia, momento, e friction. Contraction del musculos e lor relaxation, lor balancia, lor coordination, lor rhythmo, e la synchronia de lor activitates es le elementos de un satisfacente postura dynamic. Le pedes es le base e le puncto de initiation in multes del activitates relationate al postura dynamic, e le appropriate uso del pedes es essential pro un conducta efficace e salve.

Le applicationes de postura dynamic in ambular, currer, saltar, inclinar, levar, e altere activitates es presentate. Bon postura dynamic pote contribuer multo al salve e efficace execution de multes de nostre activitates durante omne periodos de nostre vitas.

10

Acquired Metatarsalgia in Women*

Stuart A. Thomson, M.D.†

INTRODUCTION

Down through the ages the female has been victimized by fashion. Grotesque footwear has been the most enduring of the dictates. The resulting foot destruction and misery are seldom blamed on the shoes; women choose rather to attribute their woes in this regard to heredity, arthritis, occupation or inherent foot qualities such as high or low arches, or bony or flexible feet.

The basic destructive qualities of women's shoes are simply the elevated heel combined with the narrow ill fit at the metatarsal head level. Thus, body weight is transmitted through the sloping foot, but most of the weight and the anchoring are borne at the metatarsal area. Major weight-bearing on the metatarsal area alone might not be so bad were it not for the inability of this part of the foot to spread to its normal maximum. However, in the narrow shoe (most of them are found to be ½ in. to 1 in. narrower than the expanded foot), the first and the fifth metatarsal heads are anchored, thus forcing the central metatarsal heads into a plantar convex position. Therefore, the second, the third and the fourth metatarsal heads begin to assume weight-bearing qualities (Fig 1) The ensuing pathologic changes are progressive and characteristic, although occasionally remote signs and symptoms are prominent.

* The author is indebted to the staff of the orthopaedic workshop in the Hospital for Sick Children for their co-operation and help in this difficult problem

† Toronto, Canada.

DEFINITION

In the past, innumerable terms have been used for symptoms and signs in the metatarsal area, both proper names and local anatomic ones. However, most of these have described local segments of a basic problem.

The term *metatarsal arch* probably should be avoided, as its existence has been doubted and argued about for years. The area with which we are concerned is the region of the metatarsal heads on the plantar surface of the female foot. Metatarsal bursitis might be a very acceptable term, since the onset of an adventitious bursa seems to be the beginning of all the trouble. Accessory calluses, bursae and corns develop gradually, and the clinical picture soon becomes more complex. Even plantar warts or sensitized small calluses may predominate. Therefore, it was felt that the well-known term *metatarsalgia* might be an acceptable and over-all title for this problem. The adjective *acquired* has been chosen, because in the vast majority of cases there is a recent history with no trouble in adolescence. The congenital cases are recognized readily, and usually they are seen during adolescence or earlier. Occurrence in the male may be of congenital or acquired origin. The incidence of metatarsalgia in the male is about 1 or 2 per cent as compared with that in the female.

THE PROGRESSIVE CLINICAL PICTURE

The early symptoms are aching and pain in the metatarsal area on standing and walk-

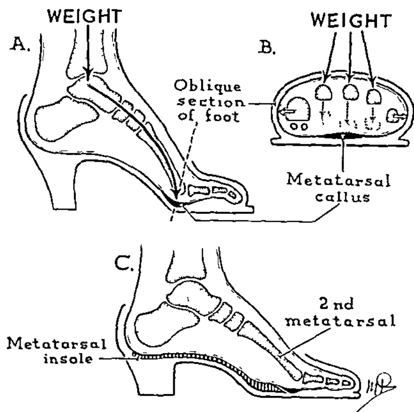


FIG. 1. (A) Showing the effects of weight-bearing in a high-heel shoe, making the metatarsal heads a terminal stump with the formation of an adventitious callus. (B) Cross section at the metatarsal head level showing how the central metatarsal heads become depressed and reversed in position when the first and the fifth heads are prevented from expansion by the narrow shoe. (C) Showing partial restoration to normal by a lower heel and wider shoe and the insertion of a metatarsal insole.

ing. Remote symptoms are not as common in these young women. The signs are loss of the metatarsal concavity with thickening, redness and tenderness of the skin. There may be no callus or bursa formation at all. Dorsal edema directly over this area may be noted toward the end of the day. In a few of the acute early cases, peroneal spasm with synovitis and clinical swelling behind the external malleolus has been noted. On the other hand, when it is associated with a breakdown in the longitudinal arch, posterior tibial tendon synovitis has been noted with swelling and pain behind the internal malleolus. It is a common experience to find that patients with these swellings about the ankles have been treated for rheumatoid arthritis. The majority of patients, however, present themselves with a much more advanced picture. Usually they insist that they have always worn "good, expensive shoes" and that they were of adequate fit. Not infrequently the presenting symptom is considerably remote from the metatarsal area, such as the dorsum of the foot, the ankle and the calf or the hip. Spontaneous changes in weight-bearing and compensatory methods of walking and standing account in good part for many of these secondary signs and symptoms.

The metatarsal area in the well-advanced case will present either a large diffuse circular skin bursa or a small oblique hornified cornlike bursa (Fig. 2). Tenderness in these bursae varies, depending on the acuteness of the condition or on local skin changes within the bursal skin.

The satellite or compensatory bursae may be prominent in some and absent in others. The common location for accessory bursa formation is on the medial plantar surface of the proximal and distal phalanx of the great toe and under the head of the first metatarsal bone (Fig. 2, *top, & bottom, left*). Less often a bursa may develop under the head of the fifth metatarsal bone (Fig. 2, *bottom, left*).

As the process advances, clawing of the four lateral toes is noted, the little toe taking the lead. This condition then is complicated

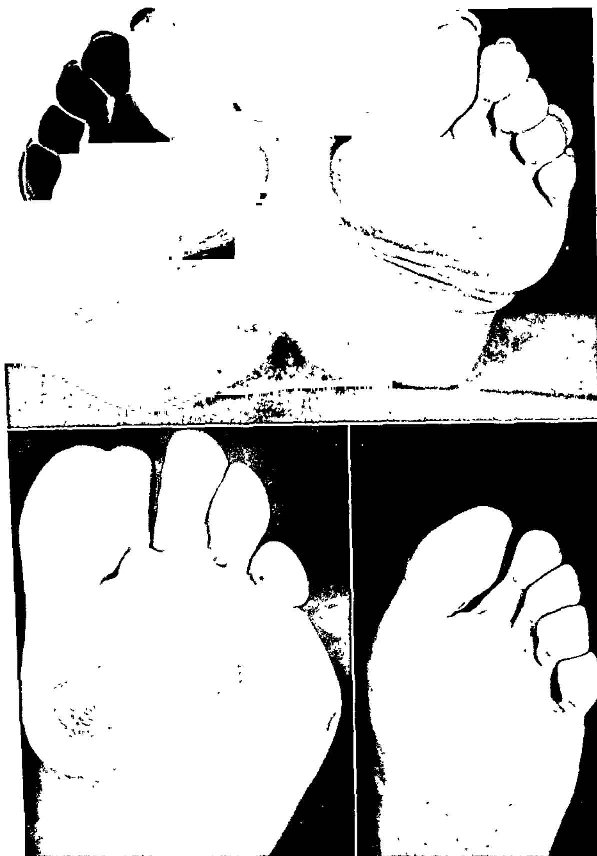


FIG 2. (*Top*) Huge metatarsal bursae with accessory bursae under first metatarsal heads and on medial plantar surfaces of the great toe. (*Bottom, left*) Medium-size metatarsal bursa with accessory ones under the first and the fifth metatarsal heads. (*Bottom, right*) Small hornified metatarsal bursa, which usually is hypersensitive.

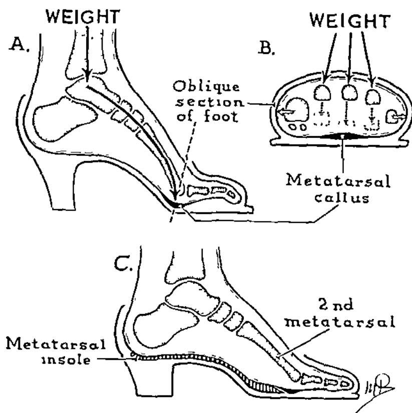


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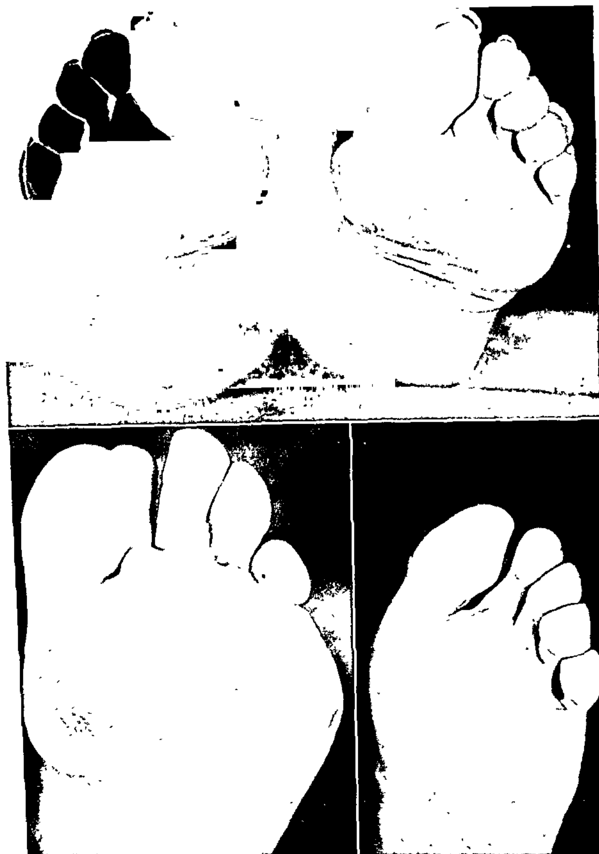


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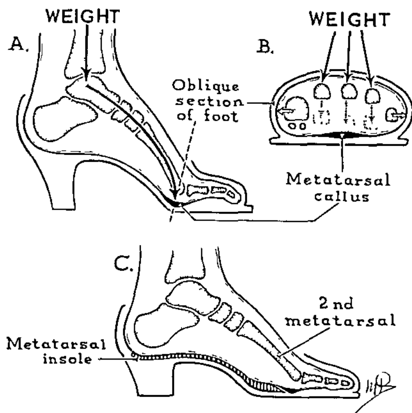


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ing. Remote symptoms are not as common in these young women. The signs are loss of the metatarsal concavity with thickening, redness and tenderness of the skin There may be no callus or bursa formation at all. Dorsal edema directly over this area may be noted toward the end of the day. In a few of the acute early cases, peroneal spasm with synovitis and clinical swelling behind the external malleolus has been noted. On the other hand, when it is associated with a breakdown in the longitudinal arch, posterior tibial tendon synovitis has been noted with swelling and pain behind the internal malleolus. It is a common experience to find that patients with these swellings about the ankles have been treated for rheumatoid arthritis. The majority of patients, however, present themselves with a much more advanced picture Usually they insist that they have always worn "good, expensive shoes" and that they were of adequate fit. Not infrequently the presenting symptom is considerably remote from the metatarsal area, such as the dorsum of the foot, the ankle and the calf or the hip. Spontaneous changes in weight-bearing and compensatory methods of walking and standing account in good part for many of these secondary signs and symptoms.

The metatarsal area in the well-advanced case will present either a large diffuse circular skin bursa or a small oblique hornified cornlike bursa (Fig. 2). Tenderness in these bursae varies, depending on the acuteness of the condition or on local skin changes within the bursal skin.

The satellite or compensatory bursae may be prominent in some and absent in others. The common location for accessory bursa formation is on the medial plantar surface of the proximal and distal phalanx of the great toe and under the head of the first metatarsal bone (Fig. 2, *top, & bottom, left*) Less often a bursa may develop under the head of the fifth metatarsal bone (Fig 2, *bottom, left*).

As the process advances, clawing of the *four lateral toes is noted, the little toe taking* the lead. This condition then is complicated

is a laced Oxford with a medium Cuban heel (Fig. 3).

The size, the shape and the position of the metatarsal pad on the insole is of vital significance in minute proportions and varies with each foot. Awareness of the fact that correction of as little as ⅛ inch is paramount. The pad should be placed so that it skirts the proximal margin of the skin bursa. It should be as wide as the bursa and yet not impinge under the first or the fifth metatarsal head. In the case of the smaller cornlike bursa, the pad should be similar in size and fit to that mentioned above. There need be no posterior extension of the pad; not only is it unnecessary, but invariably it

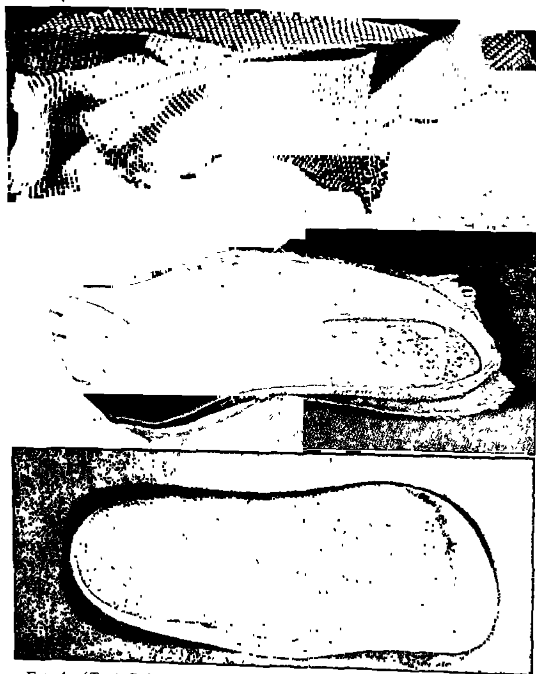


FIG. 4. (*Top*) Soft, flexible Fiberglas cloth before treatment with solutions. (*Center*) Dried fitted leather with Fiberglas base ready for final trimming. (*Bottom*) Undersurface of support after trimming (without leather covering) showing Fiberglas base.



FIG. 3. Type of shoe or pump recommended for initial treatment.

further by corn formation on the dorsal aspects of the proximal interphalangeal joints. The clawing of the toes is due most likely to prolonged spasm and ischemia of the lumbrical and the interossei muscles. Many of these patients are plagued with violent cramps in the feet, which might be attributed to the above phenomena.

Hallux valgus and bunion formation may be a complicating factor but will not be dealt with here.

TREATMENT

A woman may refuse to pocket her pride and follow good orthopaedic advice, but usually she will report back in a year or so after countless visits to podiatrists and shoe stores. In regard to podiatrists, it will be found generally that their number in any given community is in direct ratio to the lack of interest in and knowledge of the foot by the local medical doctors. It is a common experience to see patients who were sent by their doctors to corrective shoe stores or cobblers for custom-made shoes Frequently also many are referred to podiatrists not only for skin care but also for arch supports. This is a deplorable situation, not only amongst orthopaedic surgeons, but particularly amongst general practitioners.

The surgeon or the physician who sends his patient to a professional orthopaedic department of a hospital for the manufacture of arch supports would seem to be going in the right direction. However, if he personally does not supervise the fitting and the adjusting of those supports, the result most likely will be failure. Of course, no matter how good the arch support, it too will fail if the shoe does not adequately fit the foot plus the support. Therefore, the doctor must supervise the fitting of both the supports and the shoes. This supervision is rarely accomplished at one visit; it is more likely to be a matter of several visits, requiring considerable time and patience

Admittedly, in many women the finding and the fitting of an adequate shoe present difficulty, but it is not a hopeless situation. The wearing of ugly "boots" is unnecessary and need happen only in a few of the older age group with advanced pathology and broad bunion and hallux valgus formation, plus fixed clawing of the toes.

The first requisite in shoe fitting is adequate width at the metatarsal head level. This is not determined by fluoroscopy but by the simple expedient of a tape measure and common sense. It may be necessary to have a shoe stretched before satisfactory fitting is achieved It is not uncommon to have patients report that they have been through all this treatment before to no avail. However, careful analysis in such cases reveals lack of supervision and, more often than not, atrocious and highly expensive "orthopaedic equipment."

This part of the treatment is an extremely personal and vital one. Whether the patient lives in town or 100 miles away, she must be prepared to return for adjustments one to three times in the following month. These visits must be made to the orthopaedic workshop where the doctor and the workman together can see the patient. The ideal shoe

is a laced Oxford with a medium Cuban heel (Fig. 3).

The size, the shape and the position of the metatarsal pad on the insole is of vital significance in minute proportions and varies with each foot. Awareness of the fact that correction of as little as ⅛ inch is paramount. The pad should be placed so that it skirts the proximal margin of the skin bursa. It should be as wide as the bursa and yet not impinge under the first or the fifth metatarsal head. In the case of the smaller cornlike bursa, the pad should be similar in size and fit to that mentioned above. There need be no posterior extension of the pad; not only is it unnecessary, but invariably it

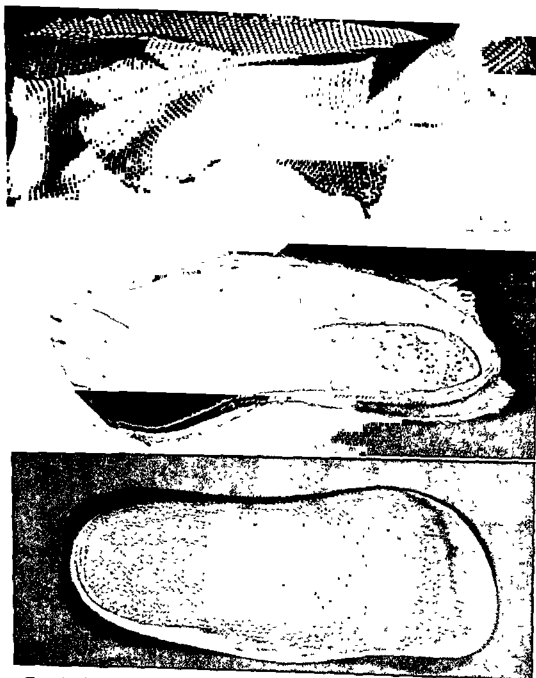


Fig. 4. (*Top*) Soft, flexible Fiberglas cloth before treatment with solutions. (*Center*) Dried fitted leather with Fiberglas base ready for final trimming. (*Bottom*) Undersurface of support after trimming (without leather covering) showing Fiberglas base.



FIG. 5. A combination support showing how cork reinforcements are added to the metatarsal pad

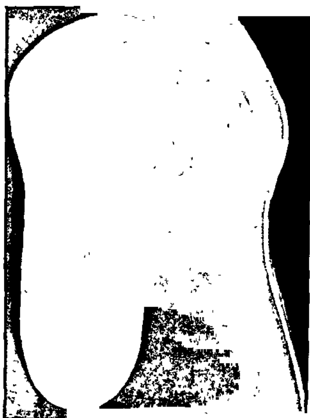


FIG. 6. Two views of a metatarsal support. *The lateral view demonstrates the* contour of the shoe.

is uncomfortable. The thickness of the pad varies with the stage of treatment: it increases in thickness and moves distally as the bursa decreases gradually in size. Failure of the bursa to disappear or its recurrence means faulty position or size of the pad.

Metatarsal bars are for temporary emergency use in severe cases, both while waiting for the insoles and during the early treatment These bars must also be inspected by the surgeon to make sure that weight-bearing has been removed, or at least decreased, at the metatarsal heads.

APPARATUS

There are countless models of arch supports, both commercial and professional. Many of them have admirable points, but very few are made specifically for the individual foot

Metal arch supports have not been used for many years. The best platemakers are unable to meet the rigid and the changing standards now required. However, the basic material of the arch support must be as rigid as metal if it is to remain in a constant position in the shoe. Softer materials and those modified by moisture and weight will shift posteriorly and curl up at the heel. Various types of treated leather with or without metal inserts have supplanted metal supports

During the past four years a very satisfactory combination of materials has been used that appears to meet most of the desirable standards. These materials are leather and Fiberglas.

A stock of wooden lasts are available in various sizes, and, in the case of the female, these lasts are also formed on a medium Cuban elevation for the heel.

The leather used is spoken of as "shoemakers' shoulder" and is top-grain leather. This comes in 20-oz. thickness and is split

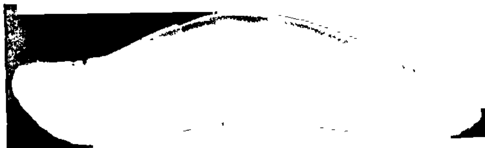


Fig. 7. Combination support with longitudinal and metatarsal raises.

to a 9-oz. thickness, which is about ⅛ inch thick. This leather is cut roughly to size and soaked in water. Next it is fitted and nailed to the wooden last and allowed to dry. When perfectly dry, it has amazing rigidity and strength. However, in order to strengthen it doubly, Fiberglas is used as a reinforcing undercoat. The Fiberglas is soft, curtainlike material until it is treated specially (Fig. 4, *top*). Varying thicknesses are used, depending on the individual needs. The Fiberglas is cut to size, and, usually, about three to five thicknesses are used. The Fiberglas cloth is manufactured from spun glass fiber and is hardened with two special solutions. The first solution is an epoxy resin* and is used as a jelling mixture. The second agent is an epoxy hardener.* The ratio used is 4 parts of the resin and 1 part of the hardener. After impregnating the Fiberglas with this mixture, it is fitted over the leather mold and allowed to harden for 24 hours (Fig. 4, *center*).

The Fiberglas falls short of the leather margins and also stops just behind the metatarsal pad area. This relationship of the leather and the Fiberglas prevents any sharp edges and allows slight movement at the junction of the main support and the metatarsal area (Fig. 4, *bottom*). The necessary additions now are made to this amazingly rigid splint. The leading edges of the leather all round the splint are shaved thin, which makes a pliable, nonirritating margin. Firm rubber metatarsal pads then are glued to the leather, and, similarly, a longitudinal pad may be used if required. When the pads need further additions, laminations of thin cork or firm sponge rubber are used, this material being more lasting and rigid (Fig. 5). These cork or rubber inserts are glued on and filed into proper contour and size. The top and the bottom of the support are covered with a thin leather called English kip.

It should now be noted that the arch support has been made not only to fit the foot but also to conform to the shoe last and the heel elevation. These precautions avoid any movement or rocking of the support in the shoe (Fig. 6).

Many years of wear may be expected from these supports, with minor repairs to the outside leather and pads (Fig. 7).

SUMMARY

This method of manufacturing arch supports was started exactly 4 years ago, and since that time 1,250 pairs have been provided. However, when one realizes the constant individuality of the two feet in this disease and the resulting attention required, it is more accurate to say that 2,500 arch supports have been made in the past 4 years and supervised by the author.

The results have been most gratifying with early loss of symptoms and gradual disappearance of both primary and secondary signs.

In conclusion, the importance of frequent personal adjustments and meticulous follow-up cannot be overemphasized.

* Manufactured by the Bakelite Co.

Acquirite Metatarsalgia in Feminas

Summario in Interlingua

Le termino "metatarsalgia" es usate pro designar le commun alterationes pathologic que occurre in le area metatarsal in feminas.

Nihil novo e nihil original es intendite sed simplemente un appello pro reactivar le interesse del orthopedistas in le diagnose e le intelligente tractamento a longe vista de ille conditiones.

Un sensibile bursa metatarso-plantar (con associate symptomas) es le causa a commun pro consultar un medico. Iste condition es le resultato de incorrecte calceatura (alte talones e compression del pede anterior). Le tractamento de iste condition consiste in le fabrication de accuratemente adjustate soleas interior metatarsal e postea le meticulose selection e adjustation del calceatura. Tamen, le plus importante phase del tractamento es le attentive e continue re-examine del patiente qui debe facer frequente visitas al officina orthopedic ubi le dispositivos de supporto es modificate in lor dimensiones e le sito de lor application. Un ben observate programma de tractamento de iste genere resulta intra alicun menses in le complete alleviamento del symptomas e le disparition gradual del bursas.

11

Hallux Varus and Metatarsus Varus

A Five-Year Study (1954-1958)

STUART A. THOMSON, M.D.*

INTRODUCTION

This work was prompted by the frequent appearance of residual deformities following variations of "medial release" operations for hallux varus and metatarsus varus. These operations concentrated on fascia and ligaments and usually removed part of the abductor hallucis muscle but rarely down to its insertion As a result, the great toe deformity persisted.

The abductor and the adductor hallucis represent two of the most important primitive muscles and really are not necessary to the human foot. One thinks of the great toe joint as having movement in one plane only; i e., plantar- and dorsi-flexion. Therefore, either these two muscles lose their functions or their insertions have drifted to aid in the normal plane of movement.

It is on this basis that these two muscles have been studied and operated upon. At the onset, not much attention was paid to the adductor hallucis, but, when its overactivity began to appear as a complication, it became apparent that its presence was of atavistic importance as well.

The Abductor Hallucis Muscle. This muscle is said to arise from the medial process of the tuberosity of the calcaneus, the plantar aponeurosis and the intermuscular septum between it and the flexor digitorum brevis It inserts by a tendon, with the medial head of the flexor hallucis brevis, into the tibial side of the base of the first phalanx of the great toe.

Dr. J. V. Basmajian, professor of anatomy at Queens University, Kingston, Ont., together with his research fellow, Dr. J. W. Kerr, kindly submitted the following additional interesting information on the abductor hallucis muscle on adult cadavers:

> Twenty-two adult feet were dissected with particular emphasis on the insertion of the abductor hallucis muscle.
>
> The abductor hallucis is the largest and strongest intrinsic muscle of the great toe. The tendon of insertion lies superficially and is formed approximately half way along the foot. At the level of the medial sesamoid the tendon measured ¼ to ½ inch in width.
>
> It was significant to note the great variation in the mode of insertion of the abductor hallucis tendon. In only 5 per cent of the specimens did the tendon lie on the medial border of the foot, and insert into the medial side of the base of the proximal phalanx as an obvious abductor.
>
> At the other end of the scale in 19 per cent of the specimens the abductor hallucis and medial head of the flexor brevis had a common insertion into the base of the medial sesamoid, with the abductor tendon lying on the plantar aspect of the foot as an obvious flexor.
>
> Between these two extremes we found that in 19 per cent the abductor tendon was on the plantar aspect of the foot and passed over the medial portion of the sesamoid, without attachment to it, and on into the base of the proximal phalanx. In 25 per cent of the cases a slip of insertion was given off the lateral side of the abductor to the medial sesamoid before its insertion on the phalanx.

* Toronto, Canada.

In another 25 per cent there was a common slip of insertion with the medial head of the short flexor into the sesamoid

On an anatomic basis it was concluded that in only 19 per cent of the cases was the abductor hallucis so placed as to be capable of true abduction. In 83 per cent of the specimens the abductor acted at the metacarpophalangeal joint to flex the great toe.

There was equal variation in the attachment of the medial head of the flexor brevis to the abductor tendon. There was found to be an attachment between the two muscles proximal to the sesamoid in every case. The insertion of the medial head of the short flexor was always into the ventral surface of the abductor hallucis tendon.

The abductor hallucis was always closely attached to the capsule of the metacarpophalangeal joint as it crossed it. In over 80 per cent of cases a slip was given off the abductor hallucis tendon superficially to insert into the

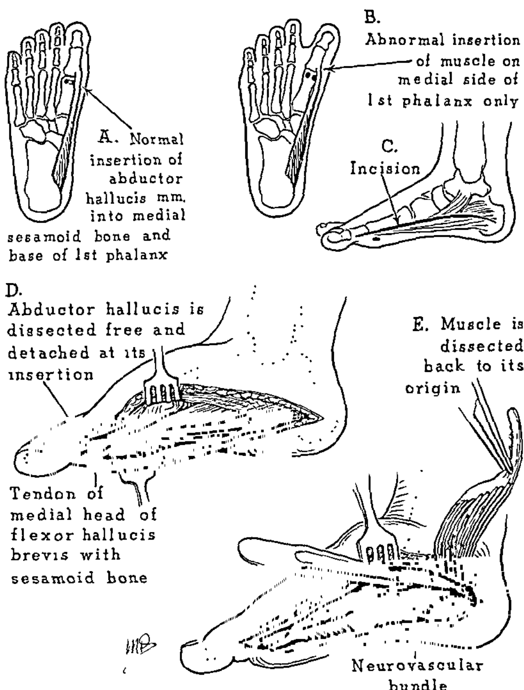


FIGURE 1

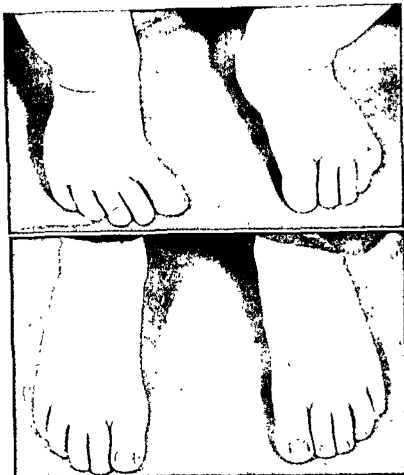


FIG. 2, T.H. (*Top*) Right-sided deformity at 1 year of age. (*Bottom*) Showing the correction 2 years after operation.

medial side of the tendon sheath of the flexor hallucis longus.

Prof. Basmajian and Dr. Kerr conclude that the abductor hallucis muscle acts more in stabilizing than in producing mobility of the great toe.

In the operating room dissections at the Hospital for Sick Children, the main part of the tendon of the abductor hallucis invariably inserted on the medial surface of the base of the proximal phalanx. Furthermore, passive contraction of the tendon produced a minimum of 75 per cent abduction movement, the balance being in flexion. However, when light pressure was placed on the great toe and the sole of the foot, the movement was 100 per cent abduction.

After detachment of the abductor hallucis tendon from the proximal phalanx it was found that the remaining fibers of the medial head of flexor brevis could still produce abduction of the great toe in a few cases.

All the foregoing observations would make one conclude that the congenital deformity of hallux varus and to a lesser degree metatarsus varus is due in part to the primitive relationship and insertion of the abductor hallucis muscle and its accessories.

DIAGNOSIS

There are two types of hallux varus and metatarsus varus:

1. The primary type, which may be readily recognized soon after birth in severe forms, or when weight-bearing begins in the less severe forms. Usually, there is no other congenital anomaly.

2. The secondary form, that associated with congenital equinovarus deformity and generally not recognized until the club foot is fully corrected. This form, therefore, usually receives attention much later, on the average, than the primary type, and, as

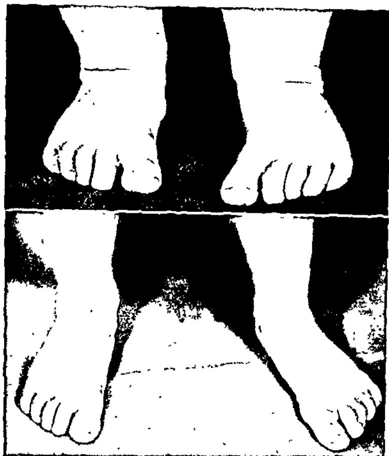


Fig. 3, P.S. (Top) Left-sided hallux varus at 1 year of age. *(Bottom)* Showing result 2 years after operation.

would be suspected, the results of treatment are not as good. The plantar surface of the foot betrays the characteristic "comma" shape or "monkey" foot appearance. The deformity is more evident with weight-bearing.

In the primary cases the first ray and hallux are notably involved, whereas in the secondary cases all the rays are inclined to be influenced in a varus position. Besides knowing about the overactivity of the abductor hallucis muscle, it is important to determine if the adductor hallucis has a primitive potential as well. This is sometimes difficult to tell, but, in most cases, by tickling the plantar surface of the great toe joint, abnormal adductor power may be detected

THE OPERATION (FIG. 1)

Hallux varus has been the primary reason for surgery in this series, in the hope that the metatarsus varus will be minimized or cured. As mentioned above, because of previous failures, it was decided to resect the entire abductor hallucis muscle.

A slightly curved skin incision is made along the entire medial side of the heel and the foot to the middle of the proximal phalanx on its medial side. The skin flaps are retracted so as to expose the complete extent of the muscle and its tendon. The tendon of insertion then is dissected off the medial side of the proximal phalanx, and, as it is dissected proximally, one may unavoidably open into the great toe joint, which is of no consequence. At this point a dissection must be made between the abductor and flexor brevis muscles, after which the entire abductor is readily resected, care being taken to avoid the plantar neurovascular bundle on its deep surface near the proximal end.

It will be noted now that the great toe has fallen back into normal position. However, the remaining fibers of the medial head of the flexor brevis must be checked by

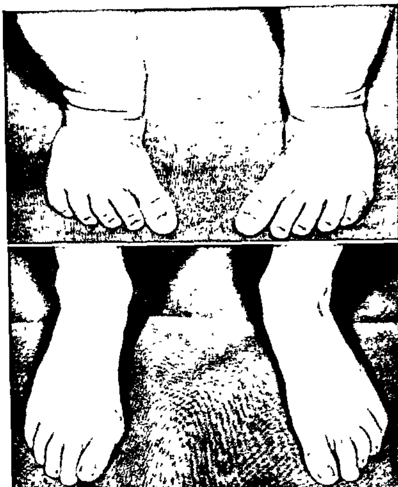


FIG. 4, W.H. (*Top*) At 9 months old, showing bilateral metatarsus varus and hallux varus. (*Bottom*) 4½ years after operation. Right foot showed overactivity of adductor hallucis, and a tenotomy was done 2 years ago.

pulling on them. If this results in any slight abduction of the great toe at all, then the entire flexor brevis must be removed as well.

The need for a tenotomy of the adductor hallucis was decided upon beforehand. If it was deemed necessary, it has been found convenient to approach it through a separate 1-inch dorsal incision on the lateral side of the great toe joint.

The incisions then are closed while the toe and the forefoot are held in the overcorrected position. Suitable dressing and padding are used, and a light below-knee plaster cast is applied.

There may be some doubt as to the need for a cast; its main virtue is in keeping the dressing secure and clean for 1 month. At the end of that time, the cast and the sutures

HALLUX VARUS AND METATARSUS VARUS. 5-YEAR SERIES. 82 CASES—114 FEET

	Number of Cases	Number of Feet	Male	Female	Age Range	Complications	Results in 100 Ft. Fair	Results in 100 Ft. Good
Primary cases . .	40	59	25	16	2 mos. to 7 yrs	9	1	49
Secondary cases	42	55	29	12	10 mos. to 10 yrs	6	9	41
Total	82	114	54	28		15	10	90



FIG. 5, B.W. (*From top*) A—Age 7 months, showing a left hallux varus. B—Showing the plantar view. C and D—1½ years after operation.



FIG. 6. M.F., age 6½ months. (*Top*) Showing left metatarsus and hallux varus. (*Bottom*) 5 years after operation. For roentgenograms of both, see Figure 7.

are removed, and the patient is allowed to carry on in a normal fashion without any corrective measures so far as the toe or the forefoot is concerned.

DISCUSSION (TABLE 1)

During the past five years, 82 cases have been operated upon. Fifty cases were unilateral, and 32 cases were bilateral, making a total of 114 feet in all. The etiology was evenly distributed, there being 40 primary and 42 secondary cases. Of the primary cases, 59 feet were operated upon and, of the secondary cases, 55 feet.

The sex differential was noticeable, there being 54 males and 28 females. The age at the time of operation ranged from 2 months to 10 years, although 29 cases were 1 year and under. In the primary cases, the age ranged from 2 months to 7 years, while in the secondary cases it ranged from 10 months to 10 years.

There were two types of complications following surgery. The more frequent one was the development of a hallux valgus due to an overactive adductor hallucis muscle. This occurred 9 times in primary cases and once in a secondary case. They all responded well to adductor tentotomies. This complication can be avoided if the adductor hallucis is assessed beforehand. The other complication was the development of a troublesome keloid formation along the line of the incision. This occurred three times, two of them in secondary cases and the other in a primary case. All required careful excision and Z-plasty procedures by our plastic division. The results were excellent. Two additional secondary cases required further sur-

gery for progressive forefoot deformities; i.e., a McCauley release and an anterior tibial transplant.

The results in the remaining 100 cases were recorded as good in 90 and fair in 10. Of the 10 cases with fair results, 1 was a primary case and 9 were in secondary cases. Good results were considered to be those in which there was a normal restoration of position and function of the great toe, to-

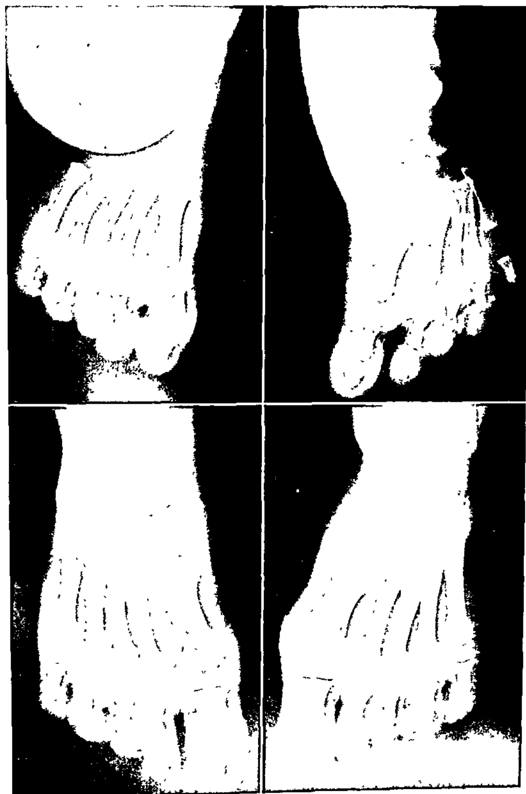


FIG 7. Roentgenograms of M F., Figure 6.



Fig. 8 M.M. (*Top*) At 1 month of age, showing right equinovarus deformity. (*Center*) Age 1½ years following correction of right club foot but now showing residual hallux varus deformity. (*Bottom*) 4 years after operation on right foot.

gether with a loss or a decrease of forefoot adduction. Fair results included some residual varus or valgus, together with some degree of metatarsus varus, none of which was considered to be to a degree requiring further surgery.

CONCLUSIONS

1. The abductor and the adductor hallucis are large primitive muscles of the foot that on occasions may be responsible for abnormal human positions and movements of the great toe and the forefoot.

2. It is important to assess any potential activity of the adductor hallucis muscle before operating on the abductor.

3. Hallux varus, both primary and secondary, is about twice as common in males.

4. Better results may be expected in the primary cases.



FIG. 9, V.R. (*Top*) Age 2 years, showing bilateral primus and hallux varus. (*Bottom*) 4 years after operation, showing correction.

Halluce Var e Metatarso Var

Summario in Interlingua

Le similitude de iste deformitate in le pede human con le non deformate pede simian ha suggerite le suspicion de un activitate atavistic del parte del musculo abductor del halluce. Dissectiones in le sala de operation e in le curso de necropsias ha confirmate iste suspicion e justificate le tractamento delineate in le presente articulo. In le pede human normal, le abductor e le adductor del halluce age probabilissimemente como stabilisatores durante que in casos del deformitate sub discussion illos es vermente abductores e adductores

Le operation de excision total del abductor del halluce, a judicar per le resultatos de iste operation in 114 pedes, pare esser un satis satisfacente manovra que produce pauc non-successos e complicationes.

12

The Author's Bunion Operation From 1931 to 1959

PAUL W. LAPIDUS, M.D.*

The author's bunion operation was first performed at the Hospital for Joint Diseases on April 8, 1931, and thus far has stood the test of time; it is still being done successfully. The details of it were published as a preliminary communication in February, 1934.

The purpose of this chapter is to describe our present-day approach to the bunion problem. Since the earliest days of his orthopaedic practice, the author has been aware of the frequent association of the metatarsus varus primus with bunions. What he was *not* aware of at that time was the fact that the same observation was made by anthropologists long before orthopaedic surgeons thought of it. Already in 1882, Leboucq pointed out that the divergence of the first metatarsal was due to the extreme angle made by the plane of the distal articular facet of the first cuneiform bone with the

* New York, N. Y.

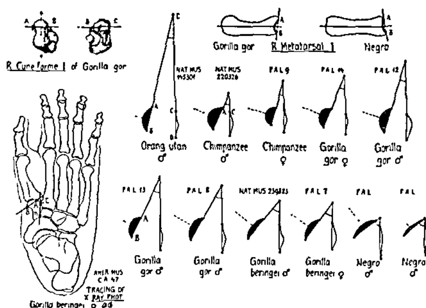


FIG. 1. Tracing of the roentgenogram of the skinned foot of an adult female mountain gorilla (beringei) showing the location of the section through the joint of the hallux and the first cuneiform. Figures on the right are accurate copies of these sections through the first cuneiform bones of various higher primates Line A-B represents a section through the center of the first cuneiform-metatarsal joint in the plane roughly parallel to the sole of the foot. Line C-D is drawn through the middle of the joint between the first and the second cuneiforms and was found always to have practically the same direction as the morphologic axis at the foot. The angle B-E-D (see orangutan) determines the medial slant of the plane of the first cuneiform-metatarsal joint. The greater this angle the less the slant and, likewise, the divergence of the first metatarsal. According to Schultz, in man this angle is 56 to 50°; in the terrestrial gorilla beringei it is 39 to 35°; in the arboreal Gorilla gorilla it is 30 to 18°; and in monkeys it is 24 to 13°. The black semicircle represents the shape of the first cuneiform-metatarsal joint, which is more ball-and-socketlike in movable hallux of the lower primates and becomes flattened in higher primate and especially in man, with the loss of mobility of the first metatarsal. (Reprinted from Human Biology, vol. 2, no 3 [chapter entitled "The Skeleton of the Trunk and Limbs of Higher Primates," by Adolph H. Schultz] by permission of the Wayne State University Press)

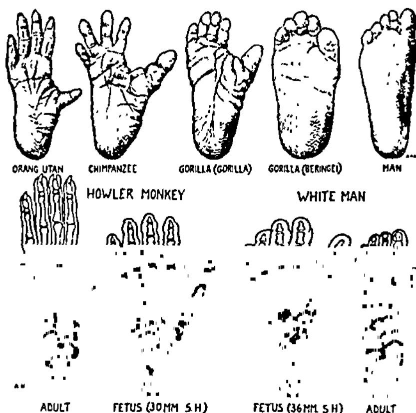


FIG. 2. Note the shortening of the hallucial ray from man to orangutan and also the increased divergence of the big toe in prehensile foot of lower primates as compared with man (upper row). The difference between the big toe in gorilla beringei and that of the Gorilla gorilla is most interesting Although they are very closely related, the first spends a great deal of time walking on the ground; therefore, his big toe resembles very closely that of man, while the hallux of the prevailingly arboreal Gorilla gorilla still retains simian features and is more like that of the chimpanzee. In the lower row is a semidiagrammatic drawing of feet of fetal and adult man, and howling monkey, showing ontogenetic reduction of the lesser digits in adult man and their increase in a grown-up monkey. Also note that the hallucial elements are almost similar in both embryos, but the first ray of the adult man becomes stouter and loses its divergence while the reverse growth changes take place in the monkey's foot. Distance from heel to second metatarsophalangeal joint is same absolute length in all 4 drawings. (Schultz, A H.: Quart Rev. Biol 1:465)

long axis of the foot This angle approaches that found in the prehensile arboreal foot of the primates (Fig. 1). In 1927, Straus, an anthropologist, who probably never saw a patient with bunions, stated.

> In the adult human, the long axis of the basal phalanx of the hallux is not, as a rule, in line with the long axis of the first metatarsal The phalangeal portion is bent toward the other digits Adduction of the hallucial phalanges is the rule for all human development, being quite as marked in the fetus as in the adult This condition cannot be ascribed to wearing boots, for it is general among the lower primates and was present in a howler fetus as well. In man it persists most likely as a relic of the days when the foot was a grasping organ and the hallux was bent as a hook toward the other toes

Figure 2 (Schultz, 1926) illustrates the trend of ontogenetic development of the foot in the howling monkey and man, and also shows the changes of the big toe as it gradually lost its prehensile functions from ape to man.

Figure 1 (Schultz, 1930) shows the changes of the first cuneiformometatarsal joint, also from ape to man The two cardinal features are (1) diminution of medial slant of the first cuneiformometatarsal joint and, consequently, also of the medial divergence of the first metatarsal, and (2) the flattening of the first cuneiformometatarsal articulation, which is more ball-and-socket-like in the mobile hallux of the lower primates.

The following table (Straus, 1927) brings out the fact that the varus of the first metatarsal, measured by the angle between the long axes of the first and the second metatarsals, is more marked in the human embryo, being 32.0° in an eight-week human fetus, and diminishes to 6.2° in an adult

ANGLE (APPROXIMATE) BETWEEN LONG AXES OF METATARSI I AND II DURING GROWTH OF MAN AND HOWLING MONKEY AND IN SOME OTHER PRIMATES

AGE	AVERAGE IN DEGREES	RANGE OF VARIATION IN DEGREES
Man		
8th week fetus	32.0	
3rd mo. fetuses	18.7	14.0–30.0
4th mo. fetuses	11.1	3.5–14.0
5–6 mo. fetuses	10 1	6 5–15.5
7–8 mo. fetuses	6.1	3 0– 9.5
9th mo. fetuses	8.9	3.0–19.5
Newborn	5.8	4.0– 8.0
Juvenile	5.0	2.0– 8.0
Adult	6 2	3.0– 9.0
Anthropoid Apes		
Orangutan, adult	46.2	42.0–49 5
Chimpanzee, juvenile	42.0	
Chimpanzee, adult	39.0	
Gorilla, juvenile	25 0	18.0–30.0
Gorilla, adult	25 0	20 0–30.0
Hylobates, adult	17.5	11.0–33.0
New World Monkeys		
Alouatta, fetus 111 mm., C R	55 0	
Alouatta, newborn	40 0	
Alouatta, adult	23.0	

Note gradual ontogenetic diminution of hallucial divergence in man from 32.0° in the 8th month fetus to 6 2° in adult. Anthropoids have a much greater angle, which reaches an average of 46 2° in prevailingly arboreal orang-utan. It is interesting to note the diminution of divergence with growth also in Alouatta (howling monkey) (Straus, W. L., Jr.: Contrib Embryol., No 101, 19:119)

man. In other words, the hallux of the human embryo has simian features that gradually are lost with growth.

The above-quoted anthropologic works seem to support the postulations made by the author in his preliminary report in 1934, that the bunion is more prone to develop in an "atavistic" foot with metatarsus varus primus. This type of foot apparently became arrested in its ontogenetic development and retained some features normally present in the human embryo and in the adult foot of the lower primates. It may be considered as a reversion to a primitive state, presenting "congenital potential predisposition toward hallux valgus formation, and thus the often observed hereditary predisposition toward this deformity can be readily understood" (Lapidus, 1934). When harelip and cleft palate are repaired, or an operation for undescended testicle is performed both being typical examples of an arrest of ontogenetic development, the surgeon attempts to complete the process that normally takes place during natural growth. By the same token, if the persistence of the metatarsus varus primus, together with hypermobility and the apelike shape of the first cuneiformometatarsal joint, allowing excessive tibial abduction of the first metatarsal in an adult man, is accepted as an arrest of development and is one of the main predisposing factors for bunion formation in a great number of patients, it is only logical to conclude that surgical repair should also consist of correction of metatarsus varus primus. If the divergence of the first metatarsal in an adult is explained as a failure of nature to complete its normal cycle of growth, then it is up to the surgeon to complete what nature failed to do, similar to harelip, cleft palate or undescended testicle.

The idea that the metatarsus varus primus is a primary factor with subsequent formation of hallux valgus is not a new one. It has been advanced by a number of orthopaedic surgeons, as can be seem from Figure 3 (after Timmer), a schematic illustration of some of the numerous operative procedures devised for correction of the bunion. Once more the author wishes to repeat that, except for the details of the operation, he does not claim priority or originality. Quite a few surgeons in the past and a number of them today approached this problem in somewhat similar manner, attempting to correct the metatarsus varus primus.

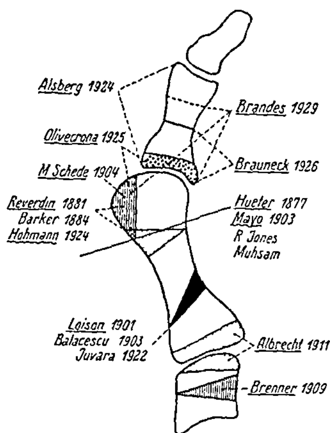


FIG. 3 Schematic drawing of various operative procedures devised for correction of bunion The name of the author and the year of description of the operation are indicated. (Timmer, H.: Die Behandlung des Hallux valgus, Leipzig, Barth)

As already stated, the degree of divergence of the first metatarsal away (tibialward) from the second depends upon the shape and the range of motion in the first metatarsocuneiform joint. The long axis of the first metatarsal forms an obtuse angle, open tibialward, with the long axis of the first cuneiform; the apex of this angle is at the first cuneiformometatarsal joint.

Osteotomy to correct an angulation deformity of any long bone is performed usually at the apex of the angulation, and not distally or proximally to it; otherwise, a bayonet-shaped deformity is produced An ankylosed knee joint with genu valgum or with flexion deformity is best corrected by an osteotomy placed right through the former line of the joint and not over the femur or the tibia. Therefore, it is the author's preference to correct the metatarsus varus primus at the first cuneiformometatarsal joint; numerous and variable osteotomies of the first metatarsal shaft, and particularly so over its distal part, never have seemed to the author to be mechanically sound (Fig. 3).

Furthermore, any osteotomies require adequate and prolonged immobilization to prevent displacement of fragments and to ensure their firm bony union. This, again, makes them undesirable. In another group of operative technics, attempt is made to utilize soft tissues (muscles, tendons or fascia) to approximate the first metatarsal head to the second and, thus, to correct the metatarsus varus primus. For a number of years it has been our preoperative routine in bunion cases to take dorsiplantar roentgenograms of the foot tightly bandaged across the metatarsal heads in addition to other routine exposures. We learned that in some cases we were unable to approximate *closely the first and the second metatarsal* heads, with some persistence of metatarsus varus primus even on tight bandaging. This was obviously due to a fixed tibial abduction contracture at the first cuneiformometatarsal joint. Consequently, is it reasonable to expect a small intrinsic muscle of the foot, as, for instance, the abductor hallucis, when it is transplanted onto the first metatarsal neck, to adduct the first metatarsal fibularward, and especially when there is fixed tibial abduction contracture present in the joint? Fascial or tendinous transplants anchored to the metatarsal necks to correct their spreading, advocated by some surgeons today, have also been tried by the author (1933) but were abandoned in favor of the bony fusion of the first metatarsocuneiform joint with creation of a bone bridging the first and the second metatarsal bases. Of course, it goes without saying that when correction of the first metatarsus varus is indicated, it is always combined with the correction of the valgus deformity of the big toe itself. In the latter procedure, not only do we depend on passive re-establishment

of balance between (tibial) abduction and (fibular) adduction of the big toe, but also we utilize the abductor hallucis muscle to supply the active power to maintain the big toe in proper alignment with the first metatarsal, as will be described below (Fig. 4).

Another group of operative technics consist of resection of the first metatarsophalangeal joint itself. The old Mayo-Küttner resection of the first metatarsal head never appealed to the author, and he is even more convinced now than he was in 1934 that "any operation creating shortening of the first metatarsal, or of the big toe, is emphatically condemned as unphysiological, and causing static and dynamic disturbance of the foot."

The resection of the base of the proximal phalanx according to the Keller-Brandes procedure has gained some popularity recently, mainly because of its simplicity and allegedly short postoperative disability. However, not infrequently after this procedure the big toe becomes a short, dangling appendage held above the ground, and the important "shove-off" function of the big toe may be lost permanently. Consequently, if one wishes to obtain as close as possible restoration of normal anatomic and physiologic relations, one cannot accept the Keller-Brandes operation.

INDICATION FOR OPERATION

Bunions are very common, especially in females, who, using their feet primarily for sex appeal, locomotor function being given only secondary consideration, succumb to the dictates of fashion and develop the deformity. The poorly fitting, narrow woman's shoe with a high heel is a factor in developing the malformation in a foot, which most of the time possesses a congenital and often hereditary predisposition toward bunion formation. In this respect, the shoe may be compared with a developing solution that only brings out the picture in a previously exposed photographic film.

We have operated upon a large number of female feet. Only a few male patients have sought surgical correction. A large percentage of bunion feet give very little, if any, discomfort, and can be treated adequately with properly fitted shoes. On the other hand, even mild bunions, especially in females, may produce a great many complaints, especially while "breaking in" a new shoe.

In addition to actual functional disturbances and disability, quite a few patients request the operation for cosmetic reasons. As a rule, we limit our surgical correction to selected cases in which functional and cosmetic consideration seem to warrant it. Therefore, although for the past many years we have operated upon a large number of patients, they represent only a small percentage of extremely numerous patients with bunions treated conservatively. Furthermore, if surgical procedure is undertaken, we do not attempt to correct the metatarsus varus primus as frequently as we did originally. We must admit that with the accumulation of larger experience through many years, we have become more conservative and in a number of cases have limited our procedure to correction of the hallux valgus alone. It has been our observation that after satisfactory correction of hallux valgus, using our modification of the Silver procedure, the varus of the first metatarsal may diminish simultaneously, provided that there is adequate mobility of the first cuneiformometatarsal joint to allow the approximation of the first and the second metatarsal heads. This mobility is estimated on roentgenograms with tight bandaging across the metatarsal heads, as already described. It has been our impression that in spite of the fact that metatarsus varus primus may be the main factor, hallux valgus developing subsequently, in a number of cases successful correction and maintenance of this correction of the big toe deformity are more important and often may be performed alone. On the other hand, additional correction of the first metatarsus varus, when it is

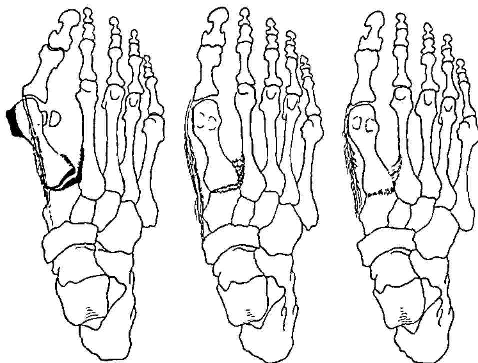


FIG. 4. Operative technic. (Lapidus, P. W.: Surg. Gynec. & Obst 58:183.) Note the plantar displacement of the abductor hallucis in bunions and its action as a plantar flexor. It is relocated along the medial aspect of the first metatarsal, and its *abduction* action is re-established.

pronounced, with first and second metatarsals forming an angle of 10° to 12° or more, may ensure better results in the long run.

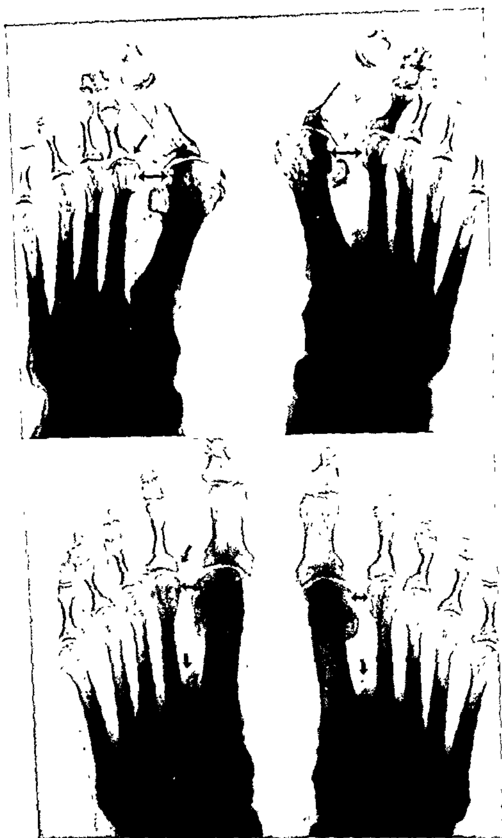
A survey of end-results of various operative procedures for correction of hallux valgus performed at the Hospital for Joint Diseases during 10 years (1931-1940) has seemed to indicate that better results were observed when metatarsus varus primus also was corrected.

We have operated upon a considerable number of patients under local anesthesia when we limited ourselves to correction of the hallux valgus alone. There is no need for a tourniquet in this procedure, which also requires less time to perform, and the postoperative recovery may be a few days shorter. On the other hand, when correction of metatarsus varus is undertaken, a tourniquet is used, and, therefore, general anesthesia is required The decision, of course, should depend on the judgment and the personal experience of the surgeon, as well as on the condition and the requirements of each patient. If the patient is not too old and is robust, and is willing to invest an extra week or two in anticipation of a somewhat better eventual result, and if the surgeon is quite confident in his hospital facilities and is fully familiar with the foot, the combination of both procedures may be indicated. Otherwise, mere correction of hallux valgus alone will be a preferable and a safer undertaking, and may also give a very satisfactory final result.

OPERATIVE TECHNIC

The present operative technic remains essentially the same as described originally in 1934 (Fig. 4). If the correction of metatarsus varus primus is planned, the operation is performed under general anesthesia. An Esmarch rubber bandage is first applied from the toes up to the lower quarter of the leg, where it is bandaged tightly over a towel and is used as a tourniquet.

The operation over the big toe joint is performed first A straight longitudinal incision about 3½ to 4 inches (9-10 cm.) long is made along the medial aspect of the big toe and the first metatarsal. The subcutaneous veins are ligated. The medial cutaneous nerve frequently seen in the wound is identified and retracted. The bursa over the bunion is opened, and further dissection is carried proximally in the same plane, as the



Figs. 5 to 8, 3 cases (L.K., B K. & A S.) following correction of metatarsus varus primus in hallux valgus (*L K.* and *A S.* also had bilateral second hammertoe operations; *in Case A.S.*, the second toes also overlapped the big [see Fig. 7, *top*]). *Fig.* 5, L.K (*Top*) Before operation. (*Bottom*) About 6 years after operation.

tissues here have very few blood vessels. The fascia covering the abductor hallucis muscle is incised longitudinally just below the insertion of this fascia along the first metatarsal shaft. A muscular belly of the abductor hallucis pops out into the wound. Its loose connection with the first metatarsal shaft may be separated by blunt dissection. As a rule, in nearly all bunions the abductor hallucis is found displaced plantarly, blending with the medial belly of the flexor hallucis brevis and acting as a plantar flexor of the big toe rather than its abductor (Fig. 4). These muscles are separated from each other also mostly by blunt dissection. The slender tendon of the abductor hallucis is then followed distally and separated from the capsule of the metatarsophalangeal joint down to its insertion onto the base of the proximal phalanx, care being taken not to sever this tendon or to open the joint capsule. The tendon is retracted plantarly, and a U-shaped flap is made in the medial capsule, with its base attached to the proximal phalanx. This flap usually is about ¾ inch (2 cm.) long and ⅜ inch (1 cm.) wide at its distal base, tapering proximally to the neck of the first metatarsal. The capsular flap is reflected distally, care being taken to dissect it from the medial aspect of the first metatarsal head, preserving its full thickness. Usually a small artery is cut over the metatarsal neck. The joint now is opened by reflecting the flap distally. The neck of the metatarsal is exposed The "sagittal groove," so well described by Haines and McDougall (1954), is noted It runs in dorsoplantar direction, separating the normal lateral cartilaginous articular surface that remains in contact with the laterally subluxated proximal phalanx from the fibrously degenerated cartilage of the medial part of the head. This groove often is quite deep in marked cases of bunion and is reddish, containing denuded rough bone. The "bunion" itself is represented usually by the dorsomedial prominence of the first metatarsal head This prominence is shaved off so that the medial, the dorsal and, to a certain extent, the medioplantar flare-up of the first metatarsal head is removed Now the medial part of the head is in the same plane and is the continuation of the cortex of the neck and the shaft of the metatarsal. Occasionally there is a dorsal prominence over the first metatarsal head, which likewise has to be shaved off. Small woodcarving chisels obtainable in any hardware store in a set, together with a sharpening stone, have been used by the author for many years and are indispensable, particularly for resection of the first metatarsocuneiform joint. They are sterilized, together with the stone, and sharpened just before the operation. When resecting the medial part of the first metatarsal head, care should be taken to preserve its round shape, and especially its part covered with the normal cartilage, without excising too much bone.

We usually replace the capsular flap and the skin and palpate through them to be sure that no bony prominences are left.

The subcutaneous tenotomy and capsulotomy then are performed over the fibular aspect of the first metatarsophalangeal joint from a dorsal approach, while the big toe is forced gently into varus (10°-15°) position A stout sharp tenotome should be used for this, and it should be inserted to hug the bone and the joint closely, as the blood vessels and nerves pass more superficially to bone in surrounding soft tissues. The medial tongue-shaped flap of the capsule is sutured to the tendon of the abductor hallucis longus with considerable tension, several No. 00 chromic stitches being used. The plantar and the dorsal capsular wounds are also closed. At the same time the abductor hallucis belly, together with its tendon, is shifted dorsally, running now along the medial aspect of the first metatarsal instead of plantarly to it, and its action as an "abductor" (tibialward) instead of a plantar flexor of the big toe now is re-estab-



FIG. 6, B.K. (*Top*) Before operation. (*Bottom*) About 6 months after operation.

lished (Fig. 4). The closing of the capsule should be performed carefully and judiciously. All capsular slack produced by resection of the medial part of the head should be removed, but at the same time the capsule should not be sutured too tightly as later to cause limitation of motion of the big toe; a good balance between abduction and adduction and dorsal and plantar flexion should be created. As a rule, the big toe in hallux valgus is in internal rotation, so that both big toenails face each other. This also should be corrected. In ordinary cases no removal of the bursa is ever attempted unless suppurative bursitis is present. In a few of our patients, there was communication of the infected bursa with the joint. In these cases, after thorough débridement of the infected tissue, we were able also to perform the bunion operation with primary union of the wound and used antibiotics postoperatively. Occasionally there is communication of the bursa with the joint also in cases without infection. In one case there was a very extensive deposition of uric acid in the bursa, and the joint surfaces were canary yellow, all impregnated with uric acid crystals. Perfect primary healing was also obtained in this 69-year-old man. The skin is closed without suturing the subcutaneous structures. If the procedure is carried out adequately, the big toe remains well corrected without any external support.

As already stated, in a number of our cases we were able to obtain very satisfactory and lasting results after this procedure alone. If, however, the correction of the metatarsus varus primus is indicated, it is carried out as a second step following completion of the operation on the big toe. A longitudinal incision about 3½ inches (9 cm.) is made along the dorsum of the first metatarsal and the first cuneiform. The first cuneiformometatarsal joint is exposed by retracting the tendon of the extensor hallucis longus medially and that of the extensor hallucis brevis laterally. The cutaneous nerve branches are identified and protected. The V-shaped space between the first and the second metatarsal bases is exposed by dissection, hugging the first metatarsal closely. The perforating plantar branches of the dorsalis pedis vessels are retracted distally and fibularward with the soft tissues when exposing the second metatarsal base. Occasionally the veins are ruptured, but we have never had any complications from that.

The cortex from the adjacent surfaces of the base of the first and the second metatarsals is removed, leaving the bone chips in situ. The first cuneiformometatarsal joint is opened on its dorsal aspect. The adjacent cartilaginous articular surfaces of the first metatarsal and the first cuneiform are shaved off. Here a small wood-carving chisel about 5 inches (13 cm.) long and about ⅜ inch (about 1 cm.) wide, is indispensable! We learned that no real wedge resection was necessary, that mere shaving off of the articular cartilage down to subchondral bone was not only enough but also essential in order to produce close linear coaptation of the resected joint surfaces and ensure prompt "primary union" of the bones.

One has to become familiar with this bean-shaped joint, which measures almost 1⅛ inches (2.9 cm.) in dorsoplantar direction, and approximately ½ inch (1.3 cm.) from side to side in its widest dimension. It also faces plantarward and medially (Fig. 1). The articular facet of the first metatarsal is slightly concave, while that of the first cuneiform is correspondingly convexed in sagittal plane. There is also a similar concavity of the first metatarsal and convexity of the first cuneiform in the horizontal plane. A snug fitting and close approximation of the resected surfaces should be obtained. A hole is then made with a shoemaker's awl

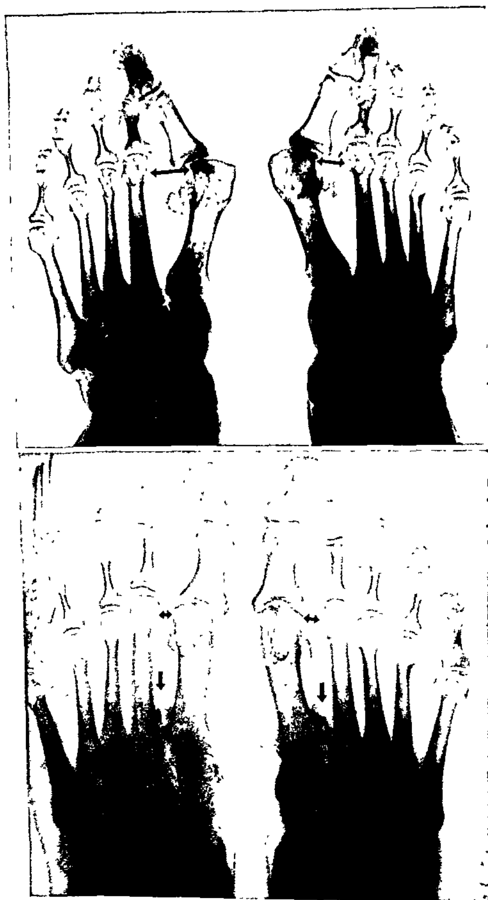


Fig. 7, A S. (*Top*) Before operation. (*Bottom*) About 6 weeks post-operatively.

over the dorsolateral part of the first metatarsal base, and No. 0 chromic catgut is passed through it, using a curved needle. Proximally, the needle is introduced through the strong dorsal ligamentous structures between the first and the second cuneiforms. When this stitch is tied, a close approximation is maintained. The pieces of bone obtained from the first metatarsal head are denuded from soft tissue and cartilage and cut in very small bone chips, which are inserted abundantly between the denuded bases of the first and the second metatarsals. They later form a bony bridge that maintains permanently the correction of the first metatarsus varus. Skin is closed with silk without suturing the subcutaneous tissues. A 5-inch (about 12 cm.) long and 5/16-inch (7 mm.) wide steel corset stay is used as a splint and is inserted along the medial aspect of the first metatarsal over well-padded dressing. The big toe is strapped to it at about 10° of varus and in slight external rotation. The first dressing should be done snugly, but not too tightly. After adequate correction, one will find on postoperative roentgenograms complete correction of metatarsus varus primus without tight bandaging across the forefoot. Likewise, the splinting of the big toe should be done most carefully in order to avoid pressure over the suture line. This is very important. One should depend primarily on an adequate surgical correction, the splinting being aimed only at maintaining it, rather than on increasing the correction.

Since the introduction of the antibiotics we have applied an antibiotic ointment routinely to the suture line* and also given the patient an antibiotic starting from one day before the operation and continuing for about 1 week postoperatively. It was noted that better wound healing was gained with prophylactic use of the antibiotics. Particularly, the wound over the bunion showed a more frequent tendency to form stitch abscesses and to separate in our early cases, and that tendency appeared to be greatly decreased by the antibiotics. There was not a single case of true infection in our latest

* Lately we have been using only Telfa.

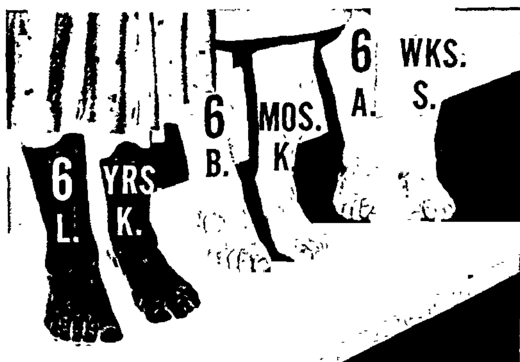
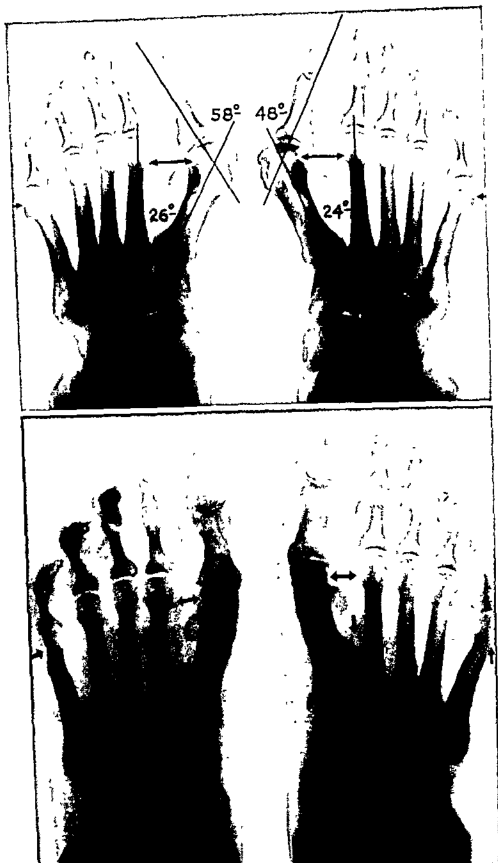


FIG. 8 Result at the time stated after operation.



FIGS 9 and 10, H.H., a 52-year-old female with metatarsus varus primus of 26° on the right and 24° on the left, and right hallux valgus of 48° and left of 58°. FIG. 9 (*Top*) Preoperative roentgenograms of both feet showing very marked deformity. (*Bottom*) Same feet about 2½ years after the operation performed on November 4, 1953. Note the heavy bone bridge between the first and the second metatarsals. Lateral prominence of both fifth metatarsal heads was also removed (arrow). (Lapidus, P. W.: Bull. Hosp. Joint Dis. **17**:404)



FIG. 10. Both feet on February 13, 1956, 2½ years after the operation. Patient still has very satisfactory correction at the present time. (Lapidus, P. W.: Bull. Hosp. Joint Dis 17:404)

(treated with antibiotics) cases. In two cases there was pressure necrosis of the soft tissue over the bunion; in one of these (not done by the author), a satisfactory result and complete healing were obtained 4 months after the operation. The second case subsequently developed involvement of the bone of the base of the proximal phalanx of one big toe that later required resection of the Keller-Brandes type. The postoperative disability lasted on and off for about 1 year, and the final result after the Keller-Brandes operation on one foot was considered to be unsatisfactory by our standards. Although we had only two cases with this complication in our large series, we recommend most careful postoperative after-care, especially *during the first postoperative week*. Usually we change the dressing on the second or the third postoperative day and replace carefully the steel corset stay, maintaining the big toe at 10° of varus. A great number of our patients have been able to go to the bathroom bearing weight on their heels on the second or the third postoperative day and were discharged from the hospital at the end of the first week after operation. Only a few patients required the use of crutches for the first week or two. A number of housewives were able to begin some light housework 2 or 3 weeks after the operation.

The stitches usually are removed at the end of 2 weeks, and snug bandaging and adhesive strapping across the metatarsal heads over an adequate padding are continued for about 4 to 6 weeks. The splinting of the big toes may be discontinued 3 or 4 weeks after the operation, depending on the amount of correction. During the first 2 weeks, there may be slight overcorrection with a few degrees of varus of the big toe. This should not be allowed to remain permanently. Control postoperative dorsoplantar roentgenograms are taken to ascertain the amount of the approximation of the first and the second metatarsal heads and the relation of the big toe to its metatarsal. Also, they show the amount of bone bridge formation between the first and the second metatarsal bases and the degree of fusion of the first cuneiformometatarsal joint. Both are usually quite solid at the end of 3 months, with subsequent roentgenograms showing further consolidation of the intermetatarsal bridge.

At first, special canvas shoes or wool socks with leather soles are worn During the second postoperative month, the patient may wear wide soft shoes or sandals. After

FIG 11 (*on facing page*), C J., a 16-year-old girl. About 2 years previously, she had been operated upon elsewhere Bilateral osteotomy (large arrows) at the first metatarsal base was performed (Mitchell's procedure) in addition to bunionectomy; also successful correction of second and third hammertoes had been performed (arrows). There was prompt recurrence of

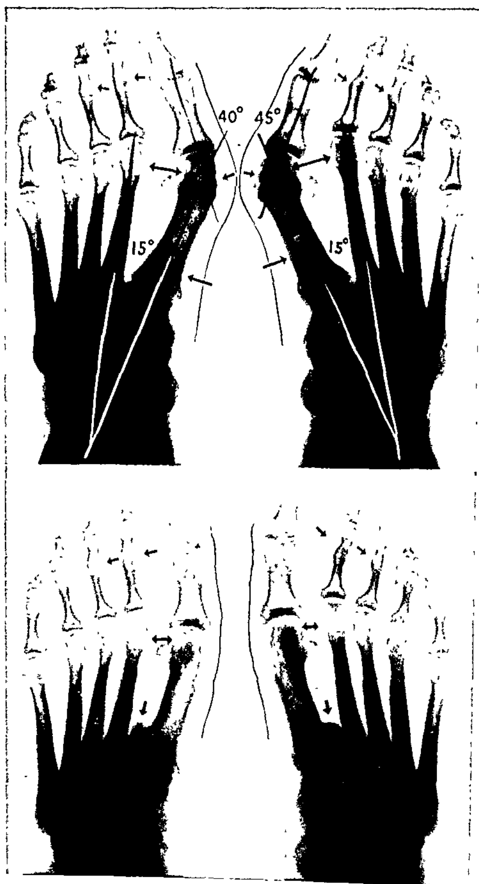


FIG. 11 (*Continued from facing page*)
bunions and extensive keloid formation over the postoperative scars (skin outline retouched over the bunions).

(*Top*) 1 year and 8 months following the first operation elsewhere. (*Bottom*) 3½ months after the second operation by the author. Note the distance between the first and the second metatarsal heads and bony bridging already present between their bases. Excellent correction is still maintained.

that time he is able to use regular well-fitted but perhaps slightly larger shoes. Housewives, as a rule, can resume their usual work about 2 months after the operation; patients having to do a great deal of walking or standing may require another week or two before going back to their 8-hour workday.

Hammertoes and overlapping hammertoes, frequently associated with bunions, usually are corrected at the same sitting. Essentially, the technic used is that described by the author in 1939, except that now he also resects the distal 3 mm. of the proximal phalanx, care being taken to remove all prominent bone edges and to establish proper alignment of the toe. He has been able to reduce the sometimes present fixed dorsal subluxation of the basal phalanx of the lesser toes by a thorough dorsal subcutaneous tenotomy and capsulotomy. After correction of the hammertoe deformity, the toe is immobilized with gently applied adhesive strapping, maintaining the plantar flexion at the metatarsophalangeal joint and dorsiflexion at the interphalangeal joints, care again being taken not to produce any ischemic changes.

SUMMARY

A very large number of our bunion cases were treated conservatively and required no surgery.

When surgical correction was indicated, we used our modification of the Silver procedure, consisting of anchoring the abductor hallucis tendon into mediocapsular flap and thereby supplying active muscular power in addition to a passive correction of the valgus of the big toe. This operation can be performed easily under local anesthesia and needs no tourniquet. It may give a very satisfactory result in cases without metatarsus varus primus or when the varus of the first metatarsal is not very extensive and is correctible.

In cases with pronounced and unreducible metatarsus varus—in other words, when there is a fixed abduction (tibialward) contracture of the first cuneiformometatarsal joint—better results were obtained following resection of the first cuneiformometatarsal joint and creating a bony bridge between the first and the second metatarsal bases in order to maintain permanent correction. This procedure is especially advisable in robust and not too old individuals.

Our present-day operative technic has been described in detail. Our operation, first performed on April 8, 1931, has been given adequate trial over the years, and our results—particularly in recent years—have been most gratifying and warrant continuation of our surgical approach in bunion problems. The popular Keller-Brandes type operation is a much simpler procedure, but it seldom, if ever, results in restoration of practically normal anatomic and functional relationship. Although our technic is somewhat more complicated, it certainly is within easy reach of any qualified orthopaedic surgeon with knowledge of the foot.

An additional week or two of postoperative recovery seems to us to be a very sound investment for the ultimate results in our cases reviewed years after the operation.

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Le Operation del Autor ab 1931 Usque 1959

Summario in Interlingua

Es discutite le tractamento del tumescentia in le bursa mucose del eminentia al pollice del pede que es hic designate per le termino anglese "bunion."

Un grande numero de nostre casos de buniones esseva tractate conservatorimente e requireva nulle intervention chirurgic.

Quando un correction chirurgic esseva indicate, nos ha servite nos de nostre modification del technica de Silver que consiste in ancorar le musculo abductor del halluce in un panno del capsula medie pro provider active fortia muscular in ultra del correction passive del pollice valge. Iste operation es facile e effectuar sub anesthesia local e non require le uso de un tourniquet. Illo produce multo satisfacente resultatos in casos sin metatarso prime varo in que le aspecto var del metatarso prime non es extense e pote esser corrigite.

In casos con metatarso marcatemente e irreducibilemente var—in altere parolas: in casos con fixate contraction abductional (verso le tibia) in le prime articulation cuneiforme-metatarsal—melior resultatos esseva obtenite per primo resectionar le prime articulation cuneiforme-metatarsal e crear un ponte ossee inter le prime e le secunde base metatarsal pro assecurar le permanentia del correction. Iste technica es specialmente recommendate in subjectos robuste e de etate non troppo avantiate.

Le technica chirurgic que nos usa currentemente es describite in detalio. Nostre operation—primo effectuate le 8 de april 1931—ha essite testate satis perennemente, e nostre resultatos (particularmente in recente annos) ha essite multo incoragiante e justifica le continue uso de nostre methodo operatori in casos de bunion problematic. Le frequentemente usate typo de operation secundo Keller-Brandes es multo plus simple, sed illo resulta rarmente—si del toto—in le restauration de practicamente normal relationes anatomic e functional. Ben que nostre technica es un pauco plus complicate, illo certo non excede le capabilitates de un qualificate chirurgo orthopedic qui possede un bon cognoscentia del pede.

Un o duo septimanas additional de recuperation postoperatori impressiona nos como un molto sage investimento de *tempore* si on considera le ultime resultatos que nos ha obtenite per nostre methodo a judicar secundo un revista del casos annos *post* le execution del operation mesme.

13

Surgery of the Forefoot in Rheumatoid Arthritis*

MACK L. CLAYTON, M.D.†

In chronic rheumatoid arthritis, deformities of the forefoot are often painful and disabling. These deformities give pain on a mechanical as well as an arthritic inflammatory basis. They present difficulty whether the arthritis is active or "burned out." The most common combination of deformities is hallux valgus and bunion, with depressed metatarsal heads and varying degrees of cockup deformity of the toes. Some toes are slightly flexible, others rigid with dorsal subluxation or dislocation of the proximal phalanges at the metatarsophalangeal joints. Some also have painful corns over the dorsum of the middle joint. Pain arises from abnormal pressure of weight-bearing on the sole or against the shoe on the dorsum. In the very early involvement, proper shoeing and arch supports may help. In advanced cases, relief of abnormal weight-bearing pressure can be obtained by surgery The marked contraction of soft tissues accompanying these deformities demands adequate bony resection for correction and pain relief. These joints are damaged, and these feet are already "weak." The toes have lost their usual function not only do these patients *lack the "take-off" to their gait, they even* avoid pressure on the forefoot. Surgery on the forefoot does not further weaken the damaged arthritic foot or further impair the patient's gait; in fact, his gait is improved.

Aufranc and Larson presented a series of chronic rheumatoid arthritic feet at the Boston Orthopedic Club in 1949. Surgery had been performed with varying degrees of metatarsophalangeal joint resections, with a resection of the proximal portion of the proximal phalanx of the great toe. It was done through multiple longitudinal dorsal incisions; the head of the first metatarsal had not been removed.

Hoffman, in 1911,[1] Thompson, in 1938,[3] and Key, in 1950,[2] also reported a number of procedures applicable to the arthritic foot.

RECENT OBSERVATIONS OF 25 FEET

Painful weight-bearing in spite of conservative therapy has been the indication for surgery. The usual procedure employed in these cases has been metatarsophalangeal joint resections of varying degrees, with or without resection of the first metatarsal head. In the later cases, the tendency has been to resect all the metatarsal heads and a portion of the necks. A portion of the proximal phalanges is also removed. The distal joints of the toes have been manipulated straight to correct "cockup" deformities. Ten toes have been corrected at one operative procedure in a number of the patients. Sometimes a metatarsal head that does not have a callus must be resected because it would remain too prominent after the offending adjacent head was removed. The tendency

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Figs. 1 to 4, I.F., aged 32. Fig. 1. Operative incision and exposure. It is easier to do the second toe first and then proceed laterally with the third, the fourth and the fifth, leaving the great toe to the last.



has been to operate on more toes at one time. The first cases were done through multiple longitudinal dorsal incisions, but now it is considered to be preferable to operate on all toes through one transverse dorsal incision at the base of the toes (Fig. 1). Depressing the cocked-up toes tends to open the incision, and the bases of the proximal phalanges are excised and the toes manipulated into the desired position. Then the metatarsal heads are easily delivered and adequately resected, and the plantar aspect is beveled to give a smooth weight-bearing surface. The tendency has been to remove increasing amounts of bone Through the single incision the exact contour of the distal metatarsals can be determined and adjusted as desired. After the bony resection is finished, the toes can be shifted into the desired position and the wounds closed, the subcutaneous tissues and the skin only being sutured. The postoperative dressing is most important and is applied to give a large compression dressing holding the toes in the desired position This dressing is undisturbed until sutures are removed after about 2 weeks. All the wounds have healed kindly. Patients have been ambulatory between 5 and 7 days. Usually they are discharged from hospital between 1 and 2 weeks. The calluses and the corns disappear with relief of abnormal pressure, and a weight-tolerant foot has been obtained.

"These feet do not stand surgery well" is a common statement, but it is contrary to the author's experience. All patients have been able to wear regular, basic Oxford shoes (medium or low heels). Often a metatarsal bar or a light inner arch support is added as indicated. There was one definite recurrence under a third metatarsal head, due to a bony spur on the distal volar aspect. These should be resected adequately and *beveled* at the time of surgery.

In this small series of 25 feet operated upon, the functional and the cosmetic results have been gratifying to both patient and surgeon (Figs. 2-5). All patients have been satisfied with the results, and usually they are very grateful for the relief of pain.



FIG. 2. (*Top*) Before operation. (*Bottom*) After operation

In 1911, Hoffmann reported an operation for "severe grades of contracted or clawed toes." Some of these cases were "infectious arthritis." He resected all metatarsal heads through a single plantar incision and outlined the basic principles for this type of forefoot surgery:

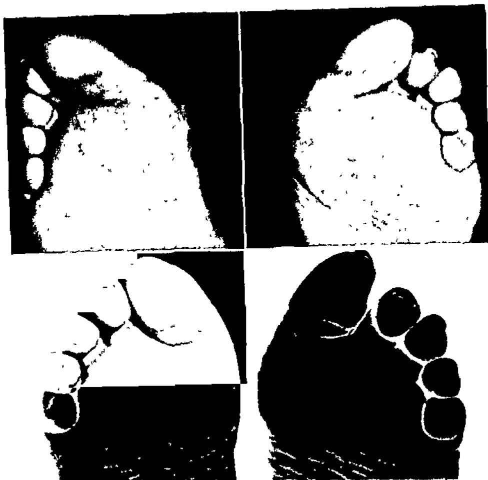
> In his [Hoffmann's] first cases, timidity, due to uncertainty of the outcome, prompted him to remove barely enough bone to allow the articular surface of the phalanx to come in contact with the cut end of the metatarsal bone. Experience taught that it is better to remove the entire metatarsal head and enough of the neck to permit the phalanx to drop into line with the resulting metatarsal stump without crowding against it. This always resulted in freely movable and serviceable joints, and in feet that were painless and, functionally, surprisingly good.

It is preferred to excise a portion of the proximal phalanges as well as the metatarsal—this may prevent recurrences—and to operate from the dorsum, but the basic principle of *adequate bony resection* remains unchanged in correcting fixed arthritic deformities of the forefoot in order to obtain a weight-tolerant foot.

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Fig. 3. (*Top*) Before operation. (*Bottom*) 9 months after operation.



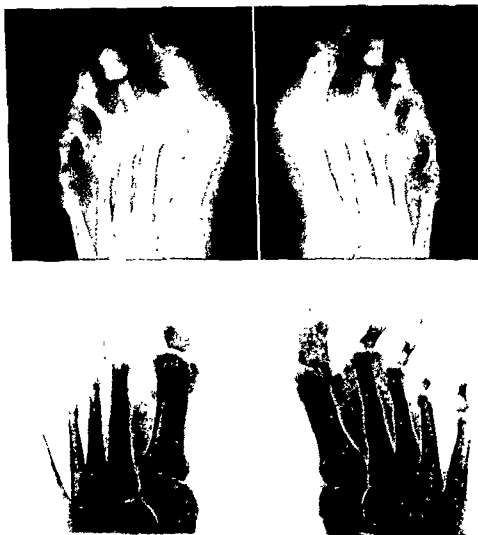


Fig 4. (*Top*) Before operation (*Bottom*) After operation. The small toe was so well aligned with removal of the metatarsal head that the proximal phalanx was not resected. This represents the minimal amount of bone to be resected from the metatarsal heads. In fact, at the present time we would probably resect more from Metatarsals 2, 3 and 4 in a similar case.

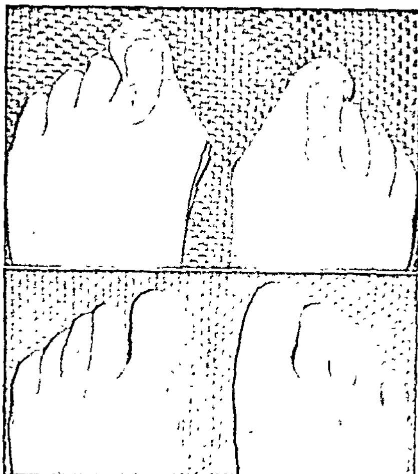


FIG. 5, D.H., age 33. (*Top*) Before operation. (*Bottom*) After operation. No surgery on Toes 4 and 5 in this case, as there was normal mobility without deformity.

Chirurgia del Parte Anterior del Pede in Arthritis Rheumatoide

Summario in Interlingua

Deformitates del parte anterior del pede es commun e grandemente invalidante in chronic arthritis rheumatoide, sin reguardo a si le arthritis es active o "consumite." Varie grados de tumescentia metatarsophalangee e de halluce valge, digitos "altiate," e deprimite capites metatarsal se incontra usualmente. Penose callositates es presente in le prominentias ossee como effecto de anormalitates in le absorption del pressura de peso o como effecto del pression del calceatura. Anormalitate de pression, usque al puncto de drainage e de infection, es notate frequentemente.

Correcte calceatura e supportos pote esser de adjuta in casos precoce, sed tal mesuras es de pauc effecto quando le deformitate ha jam devenite fixe Dolores sub peso, non alleviabile per mesuras conservative, es un indication pro le correction chirurgic del deformitate.

Le mesuras chirurgic usate ha essite adequate resectiones de osso e articulationes—capites metatarsal e phalanges proximal—insimul con manipulation del articulationes distal in le digitos minor e resection del base del phalange proximal, con o sin le capite metatarsal, in le grande digito. Le requirite mesuras chirurgic pote esser executate in un sol processo—usque a dece digitos ha essite corrigite al mesme tempore sin difficultate durante le operation o durante le periodo postoperatori. On audi frequentemente le assertion que le pedes de iste genere non es ben capace a supportar un intervention chirurgic, sed isto non es de accordo con le experientia del presente autor. Le technica chirurgic es simple. Per medio del hic-describite nove methodologia, ambulation ha essite possibile pro le patientes intra duo septimanas post le operation.

Le resultatos functional e cosmetic in le casos reportate esseva satisfacente e gratificatori ab le puncto de vista del patiente e del chirurgo.

14

The Foot in Chronic Arthritis

John G. Kuhns, M.D.*

INTRODUCTION

The feet are affected in almost all patients suffering from chronic arthritis. With persistence of weight-bearing when active disease is present, deformity and permanent articular damage often occur. Treatment of the feet frequently is delayed unduly because the progression of the disease is insidious, and the early disabilities are disregarded. While disabilities occur in all types of arthritis, the most serious and disabling ones are observed in the presence of rheumatoid arthritis. They resemble static disabilities at first, but they progress rapidly to degrees of deformity and dysfunction never observed in static disability. In osteoarthritis, the disability and the symptoms are rarely severe. In gout and in the so-called collagen diseases, it is the complications of the disease rather than the disease itself that produce the dysfunction.

The part that faulty statics and trauma play in the evolution of deformity often is difficult to measure, but these influence the development of certain types of deformities and accelerate their progress. What part trauma plays in the development of these changes in the feet usually cannot be measured with any degree of certainty. It is necessary to try to assess its influence after certain injuries, particularly industrial ones. Very rarely is inflammation of the foot alone found in chronic arthritis In most instances there are other deformities and faulty mechanical use in the weight-bearing portions of the body. Often deformities at the hip and the knee lead to disturbances in weight-bearing that aggravate disability in the foot despite the absence of arthritis.

The aims of orthopaedic treatment in the arthritic foot are (1) the prevention of deformity with preservation of function and muscular strength, and (2) the correction of deformity and the recovery of function as much as this is possible. In general, the care of the feet in arthritis differs from care in static disability, in that arthritis shows general inflammation, severe damage and rapid progression of deformity. Severe articular damage and ankylosis of joints are not found in static disabilities.

RHEUMATOID ARTHRITIS

The most serious disabilities are found in rheumatoid arthritis. Here the advancement of the disease and the progression of pathologic changes usually take place slowly. The first observable change is transient swelling of the articulations, seen most readily at the ankle and the toes. After a few months this becomes persistent and is accompanied by pain and limitation of motion. (Fig. 1, *top*)

With pain, muscular spasm occurs as a reflex phenomenon to protect the joints. Muscular spasm leads to deformities usually in flexion. In early inflammation of the joints, there are thickening of the synovial membrane and the growth of pannus over the hyaline cartilage of the joint. Muscular atrophy and progressive muscular weakness develop. Muscular weakness leads to increase of any static deformities that may be

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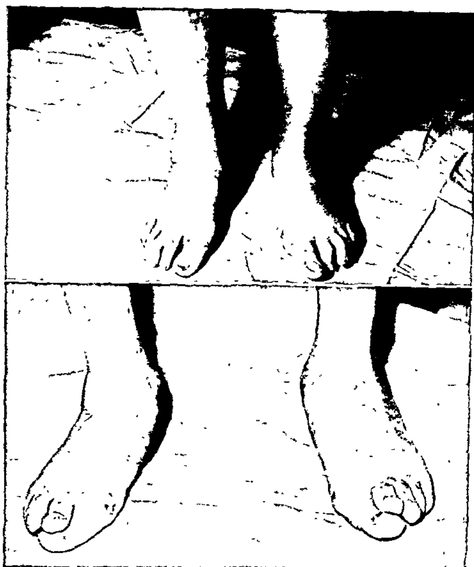


FIG. 1. (*Top*) Early rheumatoid arthritis with swelling about the ankle and on the dorsum of the foot. There is beginning flexion of the toes. (*Bottom*) Rigid valgus, with hallux valgus and hammertoe deformity in a 50-year-old patient who has had rheumatoid arthritis 17 years.

present. Relaxation of the articular capsule and ligaments may take place with early subluxation of metatarsophalangeal joints. The foot usually is rolled into valgus with spread of the forefoot. This is followed by limitation of motion with equinus and rigid valgus. (Fig. 1, *bottom*)

If weight-bearing continues, changes take place in the forefoot, hallux valgus, subluxation at the metatarsophalangeal joints and hammertoe deformities (Fig 2). In the healing of the inflammation, partial destruction, subluxation and ankylosis of the ankle and the tarsal and the phalangeal joints may result. Less common pathologic changes occur in the tendon sheaths with rheumatoid arthritis. Here granulomatous growths, adhesions, degeneration and rupture of the tendon may result. Rheumatic nodules and inflamed bursae may be found on the foot, most often near the attachment of the tendo achillis and along the outer side of the foot. In these locations they may cause pain in weight-bearing or from pressure of the shoe. Vascular changes are sometimes seen These are of two types. Firstly, the more common is venous congestion, sometimes accompanied by varicose veins. Ulcerations often are seen. They come as the result of limitation of motion and deformity. Secondly, with dependency of the legs without muscular activity most of the time, arterial changes occur in rheumatoid arthritis and allied collagen diseases, the so-called rheumatoid vasculitis with decreased lumen and lessened blood supply to the extremity.



FIG. 2. Roentgenogram of feet of patient with arthritis of 15 years' duration. Atrophy of bones with beginning fusion of tarsal joints. There is spread of the forefoot with hallux valgus, subluxation at the metatarsophalangeal joints and hammer-toe deformity.

Deformity can be prevented, but the symptoms that one finds in arthritis of the foot often are ignored. It is most unusual for an individual with pain and swelling in multiple joints to discontinue weight-bearing, even when symptoms are far advanced. If there is no static disability and the patient wears good, well-fitting shoes, symptoms often are mild, and deformity develops slowly. Arthritis rarely begins in the foot, and usually the patient is aware that he has rheumatoid arthritis long before the feet show evidence of it. It is essential to treat static disabilities of the feet in all patients with rheumatoid arthritis to prevent or to lessen the later development of arthritic deformities in this region. The first symptoms are swelling below and around the malleoli and around the metatarsophalangeal and the phalangeal joints. This is the time to protect the foot and to decrease activity. Later, there is pain on motion and on weight-bearing. With this there comes limitation of motion, first seen in the ankle joint and later in the toes and in the tarsal joints. Within a few weeks there are loss of strength and muscular spasm. The arches of the feet no longer are maintained by the muscles, and the arches become depressed. In the forefoot, a hallux valgus begins to appear with depression of the metatarsal heads, a hyperextension of the first phalanx and flexion of the other phalanges (Fig. 2). There is tenderness about the ankle and the dorsum of the foot. This usually is accompanied by muscular spasm and pain

on motion. If there is no protection, the foot generally goes into equinus with contracture of the tendo achillis. With involvement of the tarsal joint the foot assumes a valgus position, and eventually cavus also develops.

Walking becomes painful and may not be possible. As adhesions and stiffening develop, the foot usually becomes less painful on weight-bearing, and deformities become more resistant to correction. If perineal spasm develops, one sees a rigid flat foot. With cavus and rigidity, weight-bearing on unpadded areas of the foot leads to the development of painful calluses and bursae. Ulceration develops at these areas of pressure, and localized osteomyelitis may occur.

Early treatment attempts to bring the arthritis under control and to prevent or to relieve any disability in the feet. Unfortunately, this usually is difficult to carry out because the patient is unwilling to decrease or to discontinue weight-bearing. At the beginning, proper shoes with firm soles and adequate room for the swollen forefoot and a reduction in weight-bearing will relieve symptoms. If symptoms are severe, the patient should not be permitted to walk until swelling and pain have subsided. If there are muscular spasm and pain on motion, support should be provided for the foot.

For milder symptoms when weight-bearing still is permitted, the foot is protected by a firm bandage or by adhesive strapping. When symptoms persist and there is pain on all motions of the foot, a plaster cast is applied from the toes to the knee, the foot being held at right angles to the leg, with the arches of the feet well molded into the cast. This cast is worn constantly at first and is bivalved for other treatments—heat and exercises—as soon as the patient can move the foot without much pain The patient is given heat, preferably foot soaks, twice daily for periods of one half hour each. This is continued until the swelling and the soreness have subsided about the joints of the feet.

To lessen the atrophy and the weakness that always accompany inactivity, exercises are started as soon as these can be done without discomfort. These exercises start with muscular setting of the flexors and the extensors of the ankle and the toes, and proceed to exercises in balance of the foot and finally in weight-bearing. When the arches can be held properly in walking, no further formal exercise program is needed. The habit of good walking mechanics is all that is needed to maintain strength in the feet. While any inflammation is present, fatigue and pain should be avoided. A support for the arches of the feet is of value at this period. We never have seen lasting benefit from the use of massage or from vibrator machines on the feet. We prefer active exercises, but the use of these milder forms of physiotherapy in the aged and the debilitated may be helpful sometimes.

If the patient has deformity at the hip and the knee, it is common to find circulatory disturbances below the knee and around the foot. This usually is venous stagnation. If it is allowed to progress, it produces trophic ulceration on the dorsum of the foot or above the ankle. It is helped by recumbency and by elevation of the foot. A pressure bandage or an elastic stocking is used if the patient must walk. A Unna paste boot is applied. Exercises to improve the circulation are given.

When deformity has developed, this should be improved or corrected. In the mildest type, proper shoeing, supports for the arches of the feet and exercises may be enough. If the deformity does not respond to these, then weight-bearing should be stopped. Weight-bearing should not be resumed until swelling has subsided and motions of the foot are painless. In most instances, inflammation subsides most quickly if the foot is kept at rest in a well-fitting plaster cast. As soon as muscular spasm begins to subside, the cast is changed, and a cast in an improved position is applied If the deformity cannot be cor-



FIG. 3. Arthritic feet after removal of metatarsal heads for subluxation and deformity at metatarsophalangeal joints.

rected by casts, manipulation is attempted. This is performed under an anesthesia. The lower leg is held firmly, and the deformity —most commonly valgus with spasm—is corrected. Then a cast is applied in the corrected position. When the soreness from the manipulation has subsided, the cast is bivalved, and physiotherapy is resumed. Traction never has proved to be an effective means of correcting arthritic deformity in the foot.

Surgery is reserved for those feet with

recurring valgus or ankylosis in bad position for walking that do not respond to the previous measures. The aim of surgery is not a return of normal motion but a stable, weight-bearing support. The ankle is fixed at a right angle or, if there is slight flexion at the hip or the knee, at about 10° of plantar flexion. Fixation in the tarsal joints is not disturbed if the heel and the hind part of the foot are in good alignment for weight-bearing. With arthritis, one of the commonest deformities is rigid valgus with cavus. Here fusion of the astragaloscaphoid joint may relieve symptoms and prevent recurrence of the deformity. With severe deformities, most often a wedge osteotomy through the tarsal region is performed. The foot is held in a good weight-bearing position with a cast until the osteotomy has healed. Fusion of the ankle joint is indicated when the ankle has been seriously damaged by arthritis. This operation usually gives a painless stiff ankle.

Another severe deformity is a spread of the forefoot with depression of the metatarsal heads. Severe calluses develop under the metatarsal heads, and hammertoe deformity develops. The simplest and the most effective treatment is to remove the metatarsal heads through a dorsal incision (Fig. 3). For hammertoe deformity, two simple procedures are effective in the arthritic foot. The deformed toe can be straightened. The cartilage is removed from both sides of the proximal interphalangeal joint. A firm wire then is drilled longitudinally through the phalanges. This wire is allowed to remain until the toe is fused in full extension This operation is most acceptable cosmetically. It relieves symptoms and deformity, unless there is much destruction and subluxation at the metatarsophalangeal joint. With severe subluxation at the metatarsophalangeal joint, removal of the distal one half of the proximal phalanx is the preferred procedure. If the axis of the proximal phalanx is almost vertical from hammertoe deformity, it is better to remove this bone entirely

For hallux valgus it is often adequate in arthritis to remove the exostosis. When the hallux is in severe valgus, the deformity can be corrected most effectively by an osteotomy through the neck of the first metatarsal, followed by medial displacement of the distal metatarsal fragment. Fusion of the first metatarsophalangeal joint in slight dorsal extension is of value when there is much arthritic damage in this joint. There are many intricate procedures for splay foot and hallux valgus, but these have no place in the correction of deformities following rheumatoid arthritis. Occasionally one finds bony spurs or exostoses on the foot caused either by pressure or from the calcification of rheumatic nodules. When these cause pain, they should be removed. After surgery of any type on the foot, proper shoes should be worn, and support for the arches should be used. Training in proper foot balance and strengthening of the muscles is carried out until satisfactory strength and function result.

Various lesions are found in the soft tissues of the foot in rheumatoid arthritis. The most common of these is a fungus infection (epidermophytosis) between the toes and around the nails. The nails frequently become very hard and deformed. Treatment is the same as that prescribed for fungal infection without arthritis. Static ulceration often is found when the patient sits for prolonged periods of time, with stiffness at the hip or the knee. Phlebitis and eczema are other common complications associated with impaired venous circulation. This impaired venous circulation improves as the deformities at the knee and the hip are corrected. It can be helped temporarily by recumbency and elevation of the leg and by the use of a pressure bandage or an elastic stocking. When it is necessary for the patient to continue walking, a Unna paste boot is applied to the lower leg. Healing usually progresses under this. The boot generally is changed every 2 weeks.

Rheumatoid tenosynovitis is found occasionally in the tendon sheaths and invading



Fig. 4. Severe rheumatoid arthritis of tarsal joints, especially astragaloscaphoid joint.

the tendons to the toes, most commonly the extensor tendons. There is first a thickening of the tendon sheath with rheumatoid granulomas. Increased fluid and cystic enlargement of the tendon sheath are seen frequently. Later there are invasion, degeneration, adhesions and rupture of the tendon. Steroids usually are injected into the swollen tendon sheath as an early treatment, with subsidence of the swelling in about one half of them. If a large mass develops on the tendon sheath, this mass is removed surgically. If invasion of the tendon by rheumatoid granulations lead to rupture, the tendon is repaired. Often repair of the diseased tendon is helpful only temporarily, and fusion of the toe may be required later. Snapping tendon from thickening and fraying of the tendon and from thickening of the sheath just behind the head of the metatarsal bone is seen occasionally, but this rarely requires surgical correction. Dupuytren's contracture sometimes is found in the foot with rheumatoid arthritis. Its relation to the arthritis is not known. Rarely is it sufficiently severe to require treatment.

OSTEOARTHRITIS

The second most common cause of arthritic deformity in the foot is osteoarthritis. This is almost a universal finding in feet after the age of 60, but in only a small number (about 5%) are symptoms of sufficient severity to require medical attention. The changes that take place in the tarsal joints are, first, a decreased elasticity in the articular cartilage, which tends to make the gait slow and less springy. There are fissuring and gradual degeneration of the cartilage, followed by bony overgrowth about the margins of the joints. Bony overgrowth around the margins of the tarsal joints and the metatarsophalangeal joints also interferes often with the normal range of articular motion (Fig. 4). This is noticed most often at the dorsum of the first metatarsophalangeal joint, where the bony ridges may interfere with dorsiflexion particularly and lead to what is called hallux rigidus. At the insertion of the tendo achillis and at the insertion of the plantar fascia just beyond the tubercles of the os calcis, calcification

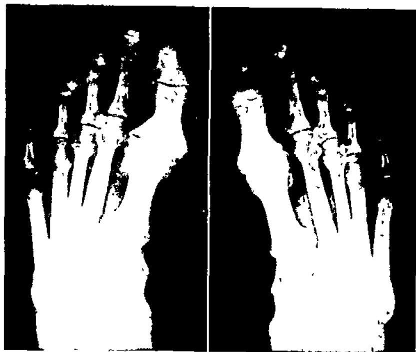


FIG. 5. Hallux rigidus, severe osteoarthritis of first metatarsophalangeal joints.

may occur along the ligaments (Fig. 5). These areas sometimes show as bony spurs, but at operative exploration one rarely finds anything more than soft masses of calcium along and within the ligaments.

Early treatment is recommended to prevent further sprain and deformity. The aging process, of which osteoarthritis in the foot is a part, cannot be prevented, only delayed. Proper shoes and good foot hygiene are necessary. If static disabilities are present, these should be corrected or the arches of the foot should be protected and supported. Foot soaks should be prescribed and exercises given to strengthen the supporting muscles of the foot. If there is much arthritis at the ankle joint, a firm elastic bandage or strapping should be used until symptoms subside. For osteoarthritis in the forepart of the foot and for hallux rigidus, a shoe with a firm sole or a long plate within the shoe will prevent hyperextension of the toes in walking and in this way prevent most of the symptoms.

Mention should be made of intra-articular injections, which are employed more frequently in osteoarthritis than in other types of arthritis These injections are given primarily for the temporary relief of pain, but they also reduce articular swelling. Injectable steroids of the cortisone group are used most commonly in suspension. These are injected directly into the joints of the foot and in rare instances into the tendon sheaths. From 25 to 50 mg. of the steroid in suspension is injected at one time under sterile precautions. The antiphlogistic and sedative effect of the drug disappears in 2 or 3 weeks. Repeated injections sometimes are needed. However, if several injections do not lead to relief, permanent support to the joint or surgery usually is required.

Little surgery is required for osteoarthritis in the feet, but orthopaedic treatment is required in all those with pain and disability. The usual findings are sprain and limitation of motion. Most of them are relieved by proper shoes—firm Oxfords with low, broad heels. Excessive weight should be decreased. Heat is used in the form of foot baths when symptoms are acute. Exercises are given to secure better weight-carriage and to strengthen the muscles of the feet. Occasionally mild support—a firm bandage, an elastic anklet or support to the arches—may be required. Moderate use, with avoid-

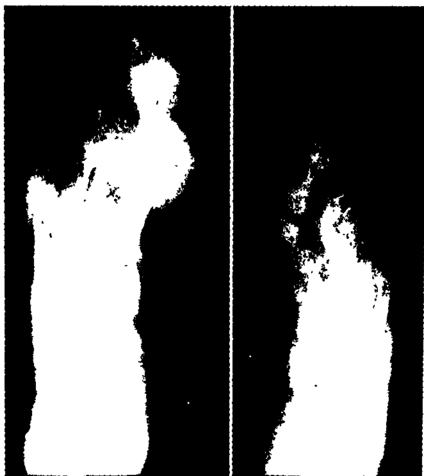


FIG. 6. Severe gout with large tophi at first metatarsophalangeal joint. The one on the left became ulcerated and required surgical removal. The tophus on the right almost disappeared with the prolonged use of uricosuric agents.

ance of fatigue in the foot, and learning to live within the limitations imposed by the osteoarthritis are an essential part of the treatment.

Surgery is employed chiefly to remove bony spurs when these cause pain on weight-bearing and to fuse severely damaged, painful joints. Bony overgrowth or long spurs may occur at any joint, but they are found most frequently at the first metatarsophalangeal joint (hallux rigidus) and at the margins of the tarsal joints on the dorsal and the medial sides of the foot. At the first metatarsophalangeal joint, removal of the spurs on the dorsum of the proximal one fourth of the proximal phalanx usually will relieve symptoms and permit painless motion. An alternate and cosmetically superior procedure is to fuse this joint in very slight dorsal extension. Simple removal of other osteoarthritic spurs is adequate. More often in osteoarthritis than in static disabilities, they will form on the inferior surface or side of the proximal phalanges. Bursa will form on the under side of the spur, and soft corns will appear on the side of the toe opposite the bony spur. Here removal of the spur will lead to the disappearance of the bursa or of the soft corn. Mention should be made of the so-called calcaneal spurs seen on the undersurface of the os calcis near the attachment of the plantar ligament. Removal of these never is necessary in osteoarthritis. Operation will reveal only soft, amorphous calcium deposits at the attachment of the plantar ligament. Treatment of the sprain in this region will lead to gradual disappearance of the calcium deposit. Sometimes a very painful ankle joint or astragaloscaphoid joint cannot be made comfortable in weight-bearing by conservative measures. In such instances, fusion of the ankle joint in slight (10-15°) equinus has been the treatment of choice. With



FIG. 7. Foot in severe scleroderma. Cavus deformity with contracture and dorsiflexion of the toes.

severe osteoarthritis of the astragaloscaphoid joint, fusion of this joint with the arch in normal alignment produces a satisfactorily functioning foot.

GOUT

The third type of articular disease causing serious disability in the foot is gout. In this disease there is often a precipitation of sodium biurate in the pedal extremity, particularly about the great toe. This deposit of urates occurs chiefly in the periarticular fibrous tissue of the first metatarsal phalangeal joint. In the acute attack, there are often very severe pain and swelling, and walking is impossible. Later there is discomfort, but walking can be performed if pressure does not fall on the inflamed area. At times, deposits of urates are found on the dorsum or other areas of the foot. Occasionally, surgery is required for the removal of these deposits if they become irritated or interfere with function. The mass is removed as completely as possible. Tendons, blood vessels and nerves often are involved in the urate deposit. They should be spared if this can be done The treatment of gout is almost entirely medical, and most large tophi can be removed or reduced greatly in size by the prolonged use of uricosuric drugs, such as probenecid

COLLAGEN DISEASES

Orthopaedic problems are presented by most patients with collagen diseases, particularly scleroderma. In this disease deformities usually are found in the hands and the feet. There is slowly increasing induration of the skin and deeper structures, often followed by atrophy and deposition of calcium in the affected tissues. The chief symptoms in the feet are stiffness and tightness. Walking becomes increasingly difficult. While there is no cure for the collagen diseases, the stiffness and the deformity can be delayed by proper support of the foot, physiotherapy and the use of steroids. With stiffness and deformity of the foot, shoes must be fitted loosely, and supports for the foot usually are required. When the progress of the disease is slow, the patients with good orthopaedic care often may continue to walk and to be active for years.

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Le Pede in Arthritis Chronic

Summario in Interlingua

Le pedes exhibi invaliditate in quasi omne patiente con arthritis chronic. Iste invaliditate es aggravate per vitios in le absorption del pressura de pesos e etiam per trauma acute. Le plus sever grados de deformitate in le pede es incontrate in casos de arthritis rheumatoide. Hic le pede exhibi deformitates flexional, adhesiones, subluxationes articular, e ankyloses. Le majoritate de istos pote esser prevenite per un precoce tractamento. In casos in que le deformitate ha devenite fixe, intervention chirurgic es frequentemente necessari. Minus pronunciate grados de invaliditate es observate in osteoarthritis, gutta, e le morbos de collageno.

15

Torsion of the Legs in Young Children

J. HIRAM KITE, M.D.*

INTRODUCTION

Torsion of the legs refers to a twisting of the entire leg or a part of the leg on its longitudinal axis. If the torsion involves the entire leg, the rotation is in the hip joint. Torsion may involve only a part of the leg. In this case it is usually between the knee and the ankle. It may be a lateral or a medial twist. The torsion may be congenital or acquired.

In lateral torsion of the entire leg, the leg is rolled out at the hip, so that the patella and the toes point outward, away from the mid-line 45° or more. In these cases the feet usually are flat.

In medial torsion of the legs, usually the parents complain that the child is pigeon-toed or bowlegged. The patellas and the feet

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FIG 1, R.B To show that sleeping in a frog position on either abdomen or back allows the legs to turn out at the hips to a laterally rotated position. The feet also turn out in a flat-foot position



FIG. 2, P.P. (*Left*) When this 8-month-old child pulls up and stands, the legs roll out at the hips. The patellas and the feet point outward about 70°. (*Right*) The only treatment that this child had was the turning of the legs medially by the mother and the wearing of swung-in shoes. The child walks with the feet straight at the age of 2.

point toward each other 30° or more. These feet usually have a good arch.

History. Fifty years ago, when a child was either knock-kneed or bowlegged, it was said that he had rickets. If the usual roentgen picture of rickets was not present, it was still assumed that he had had rickets and that the lesion had healed. When the roentgenograms failed consistently to show the lesions of rickets, it was necessary to search for some other cause for the deformity.

Etiology. The parents nearly always try to explain the deformity by saying that one or the other of them has the same deformity. In most cases, examination of the parents shows that this is not so. Occasionally a child may be born with medial torsion, but it is my belief that in most cases torsion, both lateral and medial, is acquired.

LATERAL TORSION

Lateral torsion of the legs usually is produced by the infant's sleeping constantly on his stomach in a frog, or spread-eagle, position. However, this is the safest way for a baby to sleep, in case he regurgitates. When placed on the stomach, many babies will spread the legs out 90° from the trunk. If they do not do so spontaneously, the diaper that is too large holds the legs at a right angle to the pelvis, as does a Frejka pillow, for the correction of a congenital dislocation of the hip. The baby soon becomes accustomed to this position and does not like to change to another (Fig. 1). The knees flex to a right angle, and this rolls the legs out 90° at the hips. The muscles and the ligaments about the hips soon become stretched and fixed in this position of outward rotation.

This position causes the baby to develop another deformity. The great toe and the medial border of the foot rest on the mattress, and the foot is pushed out gradually in an everted, or pronated, position. The baby soon begins to pull the feet out and up in a calcaneovalgus position. This is the only way the foot can go; the mattress blocks inversion. The anterior and the posterior tibial muscles are stretched, and the peronei muscles are shortened. The muscles, which once were nicely balanced, are thown out of balance.

Physiologically, the muscle that is stretched loses a little power, and the one

that is contracted gains a little power. Mechanically, the muscle that has to pull from around the corner, works at a mechanical disadvantage, while the muscles that pull in a straight line gain an advantage. It is probably for this reason that the peronei are able to continue to pull the foot out and up into a flat-foot position.

When the baby is placed on his back, the same frog position is assumed. The thighs are kept at a right angle to the pelvis, the knees are flexed, and gravity pulls the feet out in a flat-foot position.

When the child becomes old enough to sit alone, he sits tailor fashion with the thighs still rolled outward. When he stands, the entire leg is rolled out at the hip, so that the knee and the toes point outward from the mid-line 60° or more. He will walk with the feet in this same outwardly rotated position (Fig. 2).

Rotation Test

The rotation test is done with the child lying flat on his back (Fig. 3, *top, right*). The legs are grasped by the feet (Fig. 3, *bottom, left*), and an attempt is made to rotate the legs in and out at the hips. Normally, the legs can be turned out and in about the same amount. If lateral rotation is present, the legs can be rolled outward until the patellas and the feet both point outward about 90°. When one tries to rotate the legs medially, they can be turned medially only a little past the mid-position.

Treatment

Lateral rotation of the legs can be prevented by teaching the baby to sleep in several positions. He may sleep on the abdomen, but not always in the same position. Also, he may be placed first on one side and then on the other, alternating with the feedings. When he is on his side, with the knees flexed, the legs will be in a neutral position as regards rotation. This is true for both legs. The infant may not feel secure on his side and will try to turn. It is necessary to give his back good support.[3] A rolled-up baby blanket will provide a firmer support than a pillow. He may be placed on his back for exercise.

When the outward rotation becomes fixed, treatment will be needed to correct this. The baby is placed on his back, and the mother grasps both legs at the knees and rolls the legs medially. At first the patellas cannot be made to point medially much past the midline. She holds them in this position for about ½ minute, relaxes for a few seconds to rest the baby and herself, then turns them in again and holds them. She does this for 5 minutes morning and night. It is suggested that she make this a part of her routine when giving the baby a bath or putting him to bed.

Usually this is the only exercise that the mother is shown on the first visit. When she returns in about 6 weeks, she is checked on her stretching, and, if she is not doing it correctly, she is given another demonstration. If the child is standing and the feet are flat, the mother is shown how to turn the feet down and in to correct flat-foot deformity.[1] The child is ordered the lightest of the swung-in shoes available. Later, after he is walking, he can have heavier swung-in shoes with a Thomas heel and a long medial counter.

If the mother fails to rotate the legs medially, the lateral rotation can be corrected by sleeping in a brace (Fig. 4). This brace consists of a bar placed across the shoes that can be adjusted to rotate the legs in at the hips. Usually this will be successful in from 3 to 9 months, depending on the age of the child and the severity of the deformity. Generally it takes longer to correct the flat-foot deformity than it does the lateral rotation of the legs.

If the older child with the rigid flat feet does not respond to this treatment, a short course in casts will correct the flat-foot deformity. In only an occasional case will

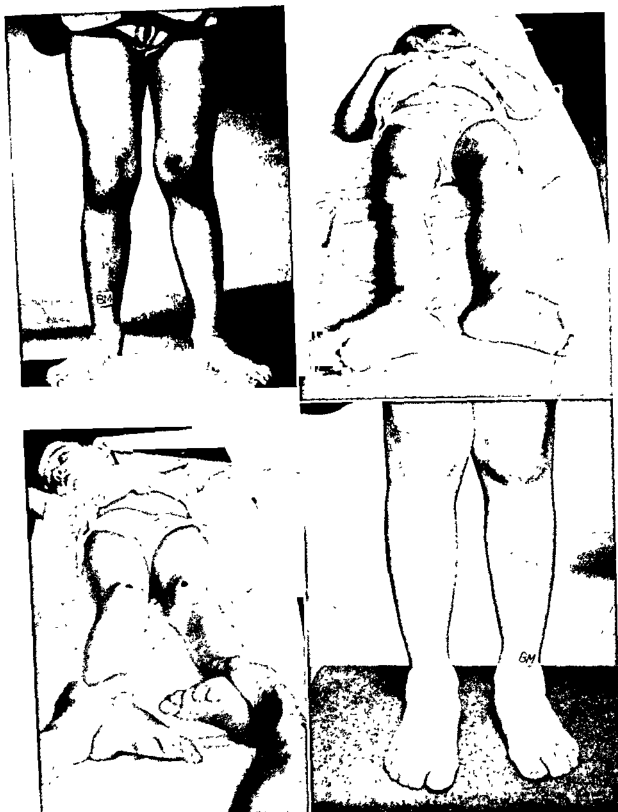


FIG 3, B.M (*Top, left*) A 3-year-old boy who had always walked with his legs turned out and was flat footed. (*Top, right*) The legs assumed spontaneously an outwardly rotated position when he was relaxed. (*Bottom, left*) The "rotation test" was done by trying to turn the legs medially. In lateral torsion cases, the legs can be turned in until the patellas point straight forward but cannot be turned in much farther. (*Bottom, right*) Shows the result 6 months later, after the legs had been rotated medially and the boy had worn swung-in shoes.

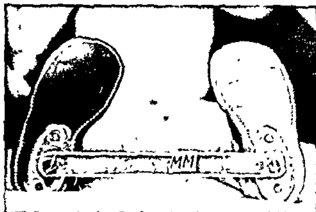


FIG. 4, M.M. Lateral rotation of the legs is corrected by letting the child sleep in shoes attached to a bar. These should be swung-in shoes, and they can be adjusted on the bar to turn the legs in more as the child becomes accustomed to the more medial position.

casts be needed. Casts are followed by swung-in shoes, and in severe cases a metal or a rubber arch support is used.

MEDIAL TORSION OF THE LEGS

Medial torsion may be divided into two types—congenital and acquired.

Congenital medial torsion was described by Nachlas,[4] who thought that it was an atavistic trait or that it was a delay in the development of the leg The deformity in these babies is noticed at birth, and it is more difficult to correct than the acquired type.

Acquired medial torsion is the type seen most frequently. Immediately after birth this baby also is placed on his stomach. Apparently he is uncomfortable until he gets his knees up under him in the fetal position. Then he will drop off to sleep. His hips and knees are flexed, and the feet are turned in toward each other, so that his weight is on his feet. He doubles up as though he were cold When he is older, he gets into this position and rocks back and forth on his feet. When he is still older and is sitting alone, he flexes his knees and sits back on his feet with his feet turned in, or he sits between his feet, as shown in Figure 5.

In studying medial torsion, we must place the children in three groups as to the location of the medial torsion. At times the torsion predominates at a single location, but usually it is a combination of two locations.

1. Medial torsion may be chiefly in the hips. We detect this by the rotation test mentioned above. The legs are grasped at the feet and gently rolled in and out at the hips. If medial torsion is present, the legs can be rotated medially until the patellas



FIG. 5, L D. When the child sits on her feet, it puts a medial twist between the ankle and the knee. When she sits between her feet, each thigh is turned medially, and the entire leg is rolled in medially at the hip (See also Fig 6)



FIG. 6, S.D. (*Left*) Child 2 years old sitting comfortably between her feet. This turns the thighs medially at the hips, so that the anterior surfaces of the thighs face each other. She also sat on her feet. (*Right*) Shows how she stands and walks.

face each other, but the legs cannot be rotated outward much past the mid-position.

This medial torsion in the hips is acquired by the child sitting between his feet, as in Figure 6. He flexes his knees and places the feet opposite each hip. This rolls the legs medially until the anterior surface of one thigh faces the other. The legs are rolled medially 90° in each hip. This becomes the child's position of comfort. Every time he crawls over to get a new toy, he always sits back between his feet in this same position.

2. Medial torsion may occur between the knee and the ankle. This is detected by letting the child sit on the edge of the table with his feet dangling (Fig. 7). Normally, the forefoot points straight forward. If there is medial torsion in the lower leg, the feet will point toward each other from a few degrees to as much as 45° or more. This deformity is first produced by the infant's sleeping with his hips and knees flexed and his feet doubled up under him. Later, when he is old enough to sit, he flexes his knees and sits back on his feet, with his feet both turned toward each other (Fig. 5). At times he sits first on one foot and then on the other. He sits more often on the left than on the right foot.

In the older child, we can tell that he sits on his feet by looking at his foot (Fig. 8). When he has been sitting on his feet, he has a bony prominence over the head of the talus and the anterior, external corner of the calcaneus. His weight comes on these two bones, and we get an enlargement of the bones from pressure similar to the hypertrophy of the head of the first metatarsal from the pressure of a narrow woman's shoe. The skin gradually becomes thick and calloused over these points of pressure. Occasionally girls are taken to the doctor by the mother with the complaint that the daughter has ugly knots on the side of her feet.

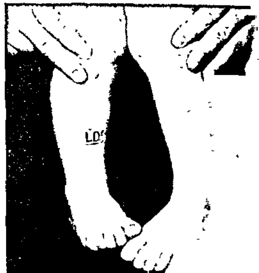


FIG. 7, L.D. To test for medial torsion between the knee and the foot, let the child sit with the legs dangling and notice whether the feet point straight forward or turn in toward each other.



Fig. 8. When the child sits on his feet with *the feet turned in under him, he* develops an enlargement over the head of the talus and the anterior external corner of the calcaneus.

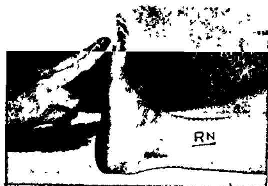


Fig. 10. His weight comes on the dorsum *of the foot, and he develops a prominence* that has been called overbone.

Sometimes a child is seen with a very short heel cord, so that the foot cannot be dorsiflexed above a right angle. At first this was difficult to explain when there was no sign of paralysis or other trouble. Watching the child sit and play with toys, supplied the answer. When he sits on his feet with the feet pointing straight back, the pressure comes on the dorsum of the foot, and he develops an enlargement on the dorsum, which has been called overbone. The Achilles tendon becomes contracted, as it does when a female wears high heels constantly (Figs. 9 & 10).



Figs. 9 and 10, R. N.
Fig. 9. When the boy *sits on his feet with* them straight back in an equinus position, he develops a short heel cord.

3. The third type of medial torsion occurs between the toes and the heel. This is metatarsus varus and is mentioned only for differential diagnosis. This deformity is in the foot itself (Fig. 11). The forefoot is adducted and inverted. There is a higher arch than normal. The great toe is widely separated from the second toe. The lateral border of the foot is convex instead of being straight. A prominence is present at the base of the fifth metatarsal and cuboid.

Occasionally it is difficult to tell at first glance whether the turning in of the feet is acquired from sitting on them or whether it is a congenital adduction of the forefoot.

The test to separate these two conditions is to hold the heel firmly and abduct the forefoot. In the case of medial torsion, the forefoot can be abducted a little past the mid-line of the foot in the normal manner. In metatarsus varus, the forefoot is stiff and cannot be abducted to the mid-line. In *medial torsion, the child voluntarily adducts* and abducts the foot normally In metatarsus varus the forefoot is constantly adducted and supinated.



FIG. 11, C.A. Typical congenital metatarsus varus deformity. This should be differentiated from the turning in of the forefoot from sitting on it.



FIG. 12, S.W. (*Left*) To show that the bowlegged deformity is more apparent than real. When the feet point straight forward in medial torsion of the lower legs, the knees must point laterally. The medial side of the leg faces forward, and the legs appear to be bowed. (*Right*) When the knees are made to point forward, as they will do in walking, the feet will be placed in a medial position. In this position the legs appear to be a little knock kneed, as they should be at this age.

SYMPTOMS

In addition to the child's being pigeon-toed, the mother frequently complains that he is bowlegged. This deformity is more apparent than real. The child tries to correct the medial torsion by walking with the feet straight. In order to do this he must turn the entire leg outward at the hips. This makes the patellas point laterally. The me-

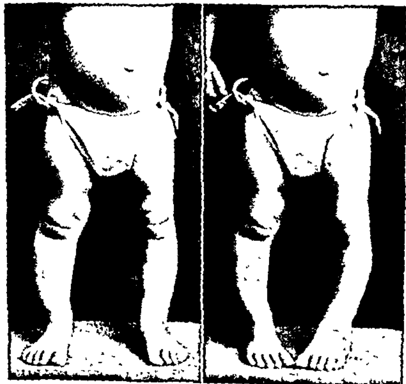


FIG. 13, R.I. (*Left*) A 2-year-old who stands with feet straight, and he does not appear to be bowlegged. (*Right*) When he walks, his feet turn in, and he appears to be bowlegged.

dial side of the leg faces forward. When the feet are placed with their medial borders touching, the knees appear to be two or three fingerbreadths apart. However, if the legs are turned medially until the patellas point straight forward, the knees are closer together than the ankles. This makes him a little knock-kneed, as he should be at this age (Fig. 12).

Usually in cases of medial torsion the child appears to be more pigeon-toed and bowlegged when he walks than when he stands (Fig. 13).

All these medial torsion cases have more lateral convexity of the lower leg than normal. This tends to make the legs look more bowed. This lateral convexity may be more severe in the congenital than in the acquired case.

For accurate diagnosis it is desirable to distinguish between the congenital and the acquired types. A helpful test is to do again the rotation test. If the legs can be turned in and out alike at the hips, the deformity probably has existed from birth. If the legs can be rotated medially until the patellas face each other, but cannot be turned out past the mid-position, the chances are that the deformity was acquired.

Roentgenograms

Many years ago it was taught that bowlegs and knock-knees were the result of rickets. The roentgenograms in cases of medial torsion never show the changes in the epiphyseal lines that were considered to be typical of rickets; they show a curve in the shadow of the soft parts, but the shafts



Fig 14, M.H (*Left*) The roentgenograms in these medial torsion cases do not present the appearance of rickets There is a running over of the metaphysis on the medial side. The soft parts show the curve, but the shafts of the tibia and the fibula are straight. The curve is produced by the slant of the epiphysial line, which is tilted toward the concave side of the curve (*Right*) When the deformity is corrected, the epiphysial lines again become transverse to the mid-line of the shaft.

of the tibia and the fibula are straight (Fig. 14). The changes in the bones occur only at the epiphyseal lines. There is a tilting of the line toward the concave side of the curve. There is some running over of the metaphysis on the medial side. When the deformity has been corrected, the epiphyseal lines again become transverse to the midline of the shaft.

Treatment

The prevention of medial torsion should be begun when the baby is first taken home from the hospital. The safest position for the baby is on his stomach. He should not always sleep with his knees doubled up under him but part of the time with the legs in the frog position. If he is alternated between the knee-chest position and the frog position, he will develop normally. Side sleeping will also help to prevent any fixed rotation deformity of the legs.

The child who sits between his feet should be made to sit part of the time tailor fashion, so as to rotate the legs laterally. This will prevent any fixed deformity. Sitting in a chair or riding a Kiddie Kar will keep the hips in a neutral, or normal, position.

If the deformity is severe and fixed, the mother is taught to grasp his knees and roll the legs laterally as far as they will go.[2] She is to hold them in this position for ½ minute; a few seconds will do no good. This stretching exercise is done for at least 5 minutes every morning and night. It may also be done for a short while when the mother changes the baby or holds him in her arms. If there is no response in several months, or if the mother does not do the manipulations, the deformity can be corrected by having the child sleep in shoes with a bar across the shoes, with the shoes turned out on the bar.

To correct the medial torsion between the knee and the foot, the habit of sitting on the feet must be overcome. This usually can be accomplished by the mother's reminding the child every time he sits on his feet to get off his feet and place them in front of him. At times a bracelet with large links is put around the ankle. This makes sitting on the feet uncomfortable.

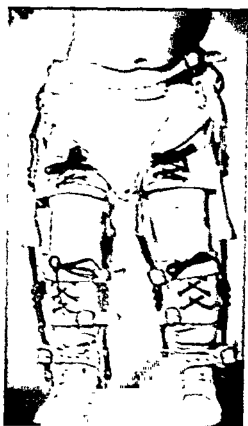


Fig. 15, J.S. Double-leg braces are used to correct the medial torsion in the very resistant cases. The lateral bars are attached to the pelvic band in such a manner as to turn the entire leg outward. There is a pad at the medial side of the knee and a strap round the medial malleolus and the lateral bar. This fixes each end of the lower leg. There is a strap round the lateral side of the lower leg that is attached to the medial bar. This corrects the lateral convexity.

When the medial torsion is well established, the same treatment is given for both the congenital and the acquired types. The mother is taught how to grasp the ankle on the medial side with one hand and the lateral side of the knee with the other, and to untwist the leg, much as she would do in wringing clothes.[2] This again is not a wiggle but a steady hold to stretch and untwist the



FIG. 16, M.P. (*Left*) To show another type of deformity in a 6-year-old boy who sits between his feet with his feet turned out in a flat-foot position. (*Center*) When he is allowed to sit to test for torsion in the lower legs, the feet turn outward. This is the result of the outward twist from sitting this way. (*Right*) He is able to walk with his knees pointing straight forward, but the feet turn out in an abducted or a flat-foot position

medial torsion. She does this at ½-minute intervals for 5 minutes twice a day.

To correct the lateral convexity, the mother should stand at the side of the lower leg, grasp the ankle and the knee, and with her thumbs make pressure on the lateral side of the leg over the fibula, at about the middle of the leg. This is done in much the same way that one would straighten a wire. This position is held about ½ minute, as in the other exercises.

A few of the cases in the congenital group will respond to this treatment, especially when the treatment is begun shortly after birth. The acquired group responds more promptly.

In those cases that do not respond or those in which the mother does not carry out these exercises, the deformity can be corrected by double leg braces. The mother is encouraged to use the exercises until the child is 15 to 18 months old and then get the braces if necessary. After the child is 2½ years old, the braces are slow to correct the deformity

The double leg braces are attached to a pelvic band (Fig. 15). The lateral bar of the brace is attached to the pelvic band so as to rotate the entire leg laterally. There are hinge joints at the knee. The bars between the knee and the foot are also set to turn the feet out a little farther. To correct the lateral convexity, there is a pad at the medial side of the knee, and at the ankle a strap around the medial malleolus and the lateral bar. This fixes each end of the leg. At the middle of the lower leg there is a broad strap around the lateral side that is attached to the medial bar. By tightening this strap, pressure is made on the lateral side of the leg to correct the lateral convexity. The brace has a normal joint at the ankle and is firmly attached to the shoe. These braces are worn only during the day, when strain is coming on the leg. The braces usually correct the deformity in from 6 to 12 months, depending on the severity of the deformity and the age of the child.

Shoes

In the cases of medial torsion, the feet turn in and usually have good arches and a

normal imprint. These children will not need special shoes. A few such children will sit between the feet and turn the feet out into a flat-foot position (Fig. 16). These feet should receive the same treatment as recommended above for flat feet.

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Torsion del Gambas in Parvulos

Summario in Interlingua

Torsion del gambas es un displaciamento circum le axe longitudinal e affice o le gamba integre o un parte del gamba. Si le torsion interessa le gamba integre, le rotation occurre in le articulation del coxa. Quando le torsion interessa solmente un parte del gamba, il se tracta usualmente del segmento inter le genu e le cavilia. Le torsion pote esser lateral o medial. Illo pote esser congenite o acquirite.

Torsion lateral es acquirite si le baby dormi super su stomacho con le gambas rectangular al trunco. Iste position promove etiam le deformitate del pede plan. Quando tal infantes prende un position sedite, illes lo face como sartores, con le gambas rolate extrorsemente.

Torsion medial pote esser presente al nascentia e es un deformitate congenite quando illo excede per multo lo que es normal. Torsion medial pote esser acquirite si le baby dormi super su abdomine con le genus flexite e le gambas plicate in le position de "genu a thorace." Usualmente le pedes es tornate al interior, con le effecto que le infante va marchar "halluce super halluce." Quando tal infantes prende un position sedite, illes reposa super lor pedes e inter illos, con le resultante production de un torsion del gamba inferior o del gamba total.

Deformitates non occurre si le infante non prende semper le mesme position in seder se. Si un del positiones describite deveni un "position de conforto," il es difficile rumper le habitude. Le tractamento consiste in alterar le position del dormir e del seder e in contratorquer le deformitate manualmente o per medio de un apparato de supporto.

16

Arthrodesis of the Foot

HARRY D. MORRIS, M.D.*

Since the earliest ankylosing procedure on the foot was recorded by Albert,[3] of Vienna, in 1878, orthopaedic surgeons have noted that arthrodesis of various joints of the foot and the ankle has proved to be increasingly useful in the treatment of paralytic and congenital deformities of the foot, pain and disability of the foot after fractures involving the articular surfaces of the joints, and static conditions of the foot due to ligamentous relaxation. The joints most frequently arthrodesed are the calcaneo-astragaloid or subtalar, the astragaloscaphoid and the calcaneocuboid. Arthodesis of these three joints is known popularly as triple arthrodesis, and addition of the tibio-astragalar joint constitutes panarthrodesis. Indications for arthrodesis of the ankle and the tarsal joints, as pointed out by Caldwell,[7] may be considered broadly to include muscular imbalance after paralysis of or injury to the muscles controlling the foot and the ankle, and painful motion followed by irreparable articular damage and bony deformity, either congenital or acquired

A brief historical review of the various procedures that have led to our present concept of arthrodesing operations about the foot should be of interest to every orthopaedic surgeon. Much of the following information was obtained from Bick's[4] excellent *Source Book of Orthopedics* Albert[3] generally is given credit for conceiving the idea of stabilization for relief of paralytic deformities of the foot, and in 1878 he described his method of denuding the articular surfaces of the tarsal bones and allowing fusion to occur during a period of immobilization. In 1889, Golding-Bird,[16] the English surgeon, reported several cases in which he had performed astragaloscaphoid fusions and also removed the navicular and, in some cases, the head of the talus for severe flatfoot deformities, and he is credited with the first surgical efforts of an arthrodesing nature to correct flat feet.

Although astragalectomies were reported to have been performed for paralytic foot deformities in the 1880's by Albert, Lorenz, Schonborn and Helferich, it was Whitman,[34] in 1901, who popularized this procedure, and he has been credited by most authors with introducing it. Whitman established definite indications and formulated a technic for this operation, with the original intention that it should be used for calcaneovalgus deformities in children between the ages of 5 and 15 years. This operation, though not an arthrodesing procedure, when performed within its indicated limitations resulted in improved function in many cases. Today, most orthopaedic surgeons believe that all the benefits of astragalectomy in paralytic feet can be obtained by much less mutilating procedures of arthrodesis and tendon transplantation, and in the young perhaps by utilizing the technic of Grice.[18] Whitman deserves much credit for stimulating interest in correction of paralytic deformities of the feet, and undoubtedly he hastened development of the arthrodesing procedures that are commonly in use today.

Apparently dissatisfied with the operation of astragalectomy, in 1908 Jones[21] described

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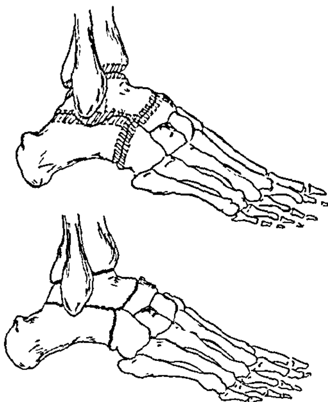


FIG. 1. Panastragaloid arthrodesis, described by Lorthoir in 1911.

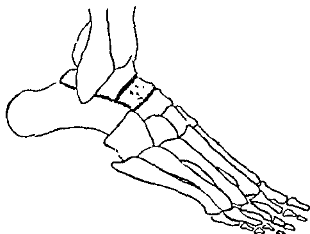


FIG. 2. Hoke's original stabilization of the foot, described in 1917, did not include the calcaneocuboid joint.

a two-stage operation for panastragaloid arthrodesis for calcaneovalgus and calcaneocavus feet, and a similar operation, described by Goldthwait,[17] was recommended for various types of paralytic deformities. Neither procedure gained widespread usage. In 1911, Lorthoir[26] reported 8 cases in which the astragalus was removed, and all cartilage was denuded and then replaced, in an effort to obtain multiple arthroses of the involved joints. In 1911, Davis[13] introduced an operation that he advocated for correction of calcaneovalgus deformity in paralytic feet and termed *transverse horizontal section*. Cook,[10] who was a member of the committee appointed by the American Orthopaedic Association in 1920 to investigate the best methods of obtaining stability of the foot in paralytic conditions, described Davis's second operation in the following way:

> *Transverse horizontal section* consists of a subastragalar arthrodesis plus a very free subcutaneous dissection of the soft structures about the ankle joint from the external and internal malleoli and from the bones of the foot whereby the foot may be displaced backwards, or the tibia, fibula, and astragalus displaced forward. No bone or cartilage is removed from the wound. The foot is moulded into the desired position and placed either at a right angle or in moderate equinus. Later, when ankylosis has taken place, and if the bones of the foot are normal, and there is no lateral motion at the ankle joint, lateral motion is prevented. The results of the operation should be a well-balanced foot, the foot displaced backwards on the tibia, fibula, and astragalus, obliteration of lateral motion, and a certain amount of definitely limited ankle motion.

This operation gained popularity in both the United States and England because it was less deforming than astragalectomy, but it had the disadvantage of requiring incisions on both sides of the foot and blindly driving instruments transversely across the articulations.

Technics for panastragaloid arthrodeses (Fig. 1) were described independently by Lorthoir,[26] Albee[2] and Steindler[32] in the 12-year period after introduction of Davis's operation, and in 1917 Hoke[21] devised a technic for subastragalar arthrodesis (Fig. 2) that is the basis of the operative technic used by most orthopaedic surgeons in the United States today, owing principally to the influence of the men who trained under the Hoke regimen. Hoke's original technic

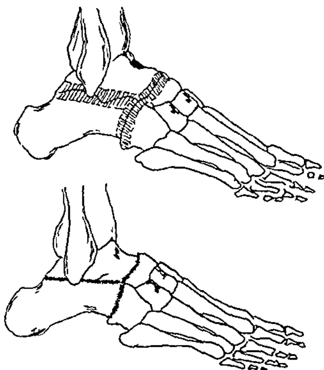


FIG. 3 Ryerson's triple arthrodesis operation, described in 1923, is probably the technic in most general use today.

consisted of removal of the head of the talus with reshaping and replacing as the correction of the deformity required, and denuding cartilage from the navicular and the subastragalar joints. Hoke was convinced that stabilization should precede tendon transplantation in the paralytic foot, since tendon transplantation alone had resulted in many failures. It is interesting to note his remarks on the qualifications that an operated paralytic foot should possess:

> First, they must look natural in shoes; second, they must be so stable that they will not turn laterally on the long axis of the foot when the patient is standing and walking; third, they must be so stable in the natural or nearly natural attitude that they do not need braces to hold them so, fourth, when barefoot they should look natural, or if that be impossible, nearly enough so to present no gross deformity.

Arthrodesis of the calcaneocuboid joint was added to Hoke's double arthrodesis by Ryerson,[29] who coined the term *triple arthrodesis,* and the operation is still so designated (Fig. 3)

In 1916, Dunn[14] devised a slightly different procedure for correction of calcaneovalgus deformities. In 1921, Lambrinudi[25] devised a special type of triple arthrodesis designed to correct paralytic equinus feet. This technic is used frequently today when no dynamic muscle transplant is available to dorsiflex the foot. In 1927, Miller[27] devised an operation for correction of flat feet in adolescence. This consisted of arthrodesis of the scaphocuneiform joint and the joint between the first cuneiform and the base of the first metatarsal. Hoke[22] treated the same condition by arthrodesis of the scaphocuneiform joint (Fig. 4) with a bone graft. This procedure was described in 1931.

It was not until about 1935, after reports by Speed and Boyd,[30] Watson-Jones[33] and Steindler,[32] that tibiotalar arthrodesis for relief of pain after malunited fractures about the ankle became widely used, and following the work of Conn,[9] in 1935, on the treatment of os calcis fractures and, later, that of Gallie,[15] of Toronto, that the principles of arthrodesis used for so many years in the treatment of paralytic deformities were applied to painful articulations of the foot after fractures with resulting traumatic arthritis. Among the more recent technics that deserve mention is the tibiotalar arthrodesis of Blair[5]

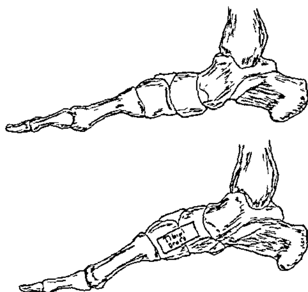


FIG 4 Hoke's scaphocuneiform arthrodesis for relaxed flat foot, introduced in 1931.

and the ankle fusion of Adams[1] utilizing a transfibular approach and the fibula as a fixation graft. The extra-articular arthrodesis of the subastragalar joint for the correction of flat feet in children was described by Grice[18] in 1952, and the modified technic for posterior arthrodesis of the ankle and the subastragalar joint was described by Staples[31] in 1956.

Although many surgical technics have been devised for arthrodesing the ankle and the tarsal joints, the technic in general consists of removal of the cartilage and excision of sufficient bone to correct the existing deformities, and use of either chips or bone grafts, with or without internal fixation of various types, in order to promote the most rapid fusion and hold the position of the articulation involved. Certain fundamental concepts should be borne in mind before arthrodesis of the foot or the ankle is contemplated if the deformity is severe. As is frequently the case in congenital deformities and neurogenic disorders with muscular imbalance, preliminary correction of the soft-tissue deformities, either by wedging in a plaster cast or by section of soft tissue, is indicated in order to prevent removal of a large amount of bone at the time of stabilization. In paralytic conditions, arthrodesis generally should precede any tendon transplantation, since correction of the deformity is essential to successful function of the transplant and cannot be accomplished by the transplant itself; nor, in most instances, can transplantation of tendons alone be relied upon to secure stability. The only exception to this rule, in my opinion, is in extremely young children who have not acquired sufficient bone age for an arthrodesing procedure in which an unopposed tendon is constituting a deforming factor. In this instance, transplantation can be done preceding stabilization if the foot cannot be held satisfactorily in an apparatus until the optimum time for stabilization has been reached. Arthrodesis of the tarsal joints can rarely be performed satisfactorily before the age of 8 years, and one should be cognizant of the epiphysial lines, particularly in the lower tibial epiphysis in arthrodesis of the ankle in children, although central bone-grafting technics[20] have been devised that eliminate the fear of arresting epiphysial growth even in this situation. Procedures for arthrodesing the joints about the foot can be classified easily into five groups:

1. Tibiotalar arthrodesis (ankle fusion)
2. Triple arthrodesis (talocalcaneal, talonavicular and calcaneocuboid)
3. Pantalar arthrodesis (panarthrodesis) (tibiotalar, talonavicular, talocalcaneal and calcaneocuboid)
4. Navicular cuneiform arthrodesis (flat-foot operation)
5. Arthrodesing operations with special indications: (a) tibiotalar arthrodesis of Blair; (b) extra-articular arthrodesis of the subastragalar joint of Grice.

ARTHRODESIS OF THE ANKLE (TIBIOTALAR ARTHRODESIS)

Arthrodesis of the ankle is indicated to relieve the pain and the disability of traumatic arthritis, generally the result of malunited fractures, or dislocations about the ankle joint, occasionally to relieve the disabling pain of other types of arthritis and tuberculosis, and to correct paralytic calcaneous valgus equinus, which will be discussed under panarthrodesis. I prefer an anterior approach between the tendons of the extensor hallucis longus and the extensor digitorum longus, the anterior tibial vessels being retracted laterally. Reflection of the periosteum and capsular division provides adequate exposure, including the articular portions of the malleoli. Removal of a sliding bone graft from the lower end of the tibia across the articular surface of the tibial portion of the joint enhances the exposure. All cartilage is removed from the superior surface of the talus and the inferior articular surface of the tibia, including the cartilage on the articular surface of both internal and external malleoli. A slot then is cut in the supe-

rior portion of the talus to receive the sliding bone graft. The graft is reversed end on end and driven into the prepared bed in the talus, with the ankle in the desired position for fusion. Excellent internal fixation can be obtained by use of two stainless steel staples inserted from both medial and lateral malleoli into the talus (Fig. 5). Cancellous bone chips secured from the tibia are used to pack the spaces between the joint and between the denuded malleoli and the talus. In children whose epiphyseal line is still open, the central bone graft technic, as devised by Hatt,[20] is effective and will not cause premature closure of the epiphysial line. If possible, it is most desirable to wait until the epiphysial line has closed. The transfibular technic described by Adams is excellent. However, I have encountered considerable difficulty in correcting a valgus or a varus deformity of appreciable degree by this technic. The compression arthrodesis of Charnley[3] seems unnecessarily complicated, as a high percentage of successful arthrodeses can be secured by the other methods described. Equinus of 5° to 10° generally is considered to be the best position for a fused ankle, although some believe that arthrodesis at a right angle, particularly for men, will give a better gait. Women who wear high heels require more equinus than men. Hallock[19] suggested 5° of equinus for each ¾ inch of heel height. Postoperatively the leg is encased in a plaster cast extending above the flexed knee. This usually can be replaced with a walking boot after 4 to 6 weeks. External fixation may be discarded after 12 weeks, depending, of course, on demonstration of satisfactory roentgenographic evidence of fusion.

TRIPLE ARTHRODESIS

Triple arthrodesis is a basic operation indicated in lateral instability of the foot and deformity after poliomyelitis and other neuromuscular disorders. It is particularly effective when subsequent dynamic tendon transplantation can be employed to eliminate a deforming factor or to substitute inverters or everters of the foot to assist in plantar flexion or dorsiflexion of the foot after stabilization. It is indicated for resistant congenital deformities and in cases of severe relaxed feet that have failed to respond favorably to conservative care, and it can be performed as prophylaxis against disabling pain in the feet in adults as a result of such conditions of the feet during adolescence. It can be used in primary disabling arthritis of the tarsal bones and traumatic arthritis of a secondary nature, especially in complicated fractures about the os calcis involving the subastragalar and the calcaneocuboid joints.

I prefer a modified Hoke procedure, as taught me by Clarence Crego, Relton McCarroll and, later, Guy Caldwell, the last named one of Hoke's trainees. This consists essentially of an oblique lateral incision extending across the subtalar fossa, removal of the adipose and the ligamentous tissues from the fossa, osteotomy of the talus at the base of the neck with removal of the head and the neck of the talus, which is the principal factor in securing adequate exposure, osteotomy of the anterosuperior lip of the os calcis to allow access to the calcaneocuboid joint, denuding the calcaneocuboid joint or removing suitable wedges for correction of the deformity, removal of cartilage from the subtalar joint, denuding the posterior articular surface of the scaphoid and replacing the denuded talar head at the close of the procedure The fact that the replaced head and neck of the talus can be shortened or modified, according to the demands of correction of the structural deformity, is one of the outstanding advantages of this technic, I have had no difficulty in revascularization of the replaced talar head. The straight lateral approach minimizes skin slough if reasonable care is taken to prevent trauma to the cutaneous edges, especially with the use of sharp rake retractors. Langenbeck periosteal elevators, bent with a small bending iron to increase the curve at the end of the instrument, can be slipped readily behind the neck of the talus to protect the soft tissues on the

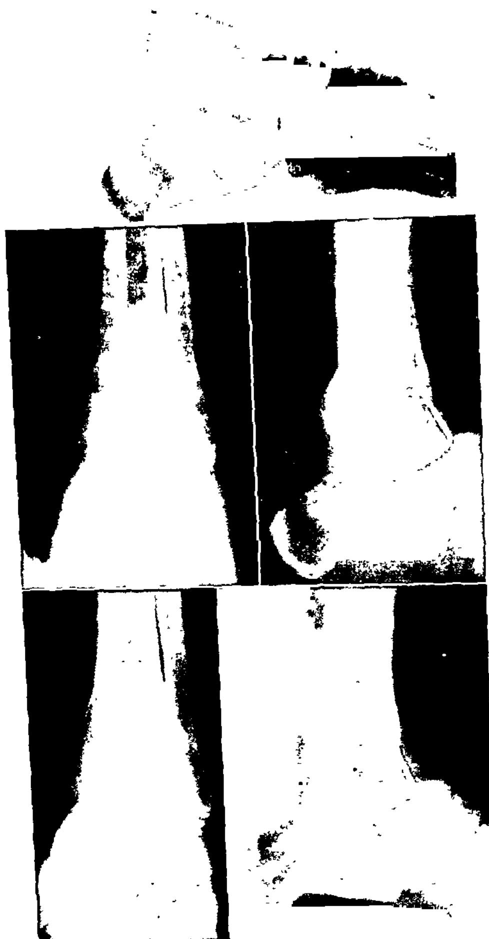


Fig. 5. Arthrodesis of ankle with sliding bone graft and staple fixation. (*Top*) Preoperative fracture of talus with early aseptic necrosis of body. (*Center*) Immediately after operation. (*Bottom*) Four months postoperatively arthrodesis is complete.

medial side and give exposure while the osteotomy is being performed through the neck. The same instrument can be passed posterior to the subtalar joint and inserted far enough on the medial side of the joint to protect the posterior tibial artery when bone resections are made through the subtalar region.

The Hoke technic can be modified to give all the advantages of the Lambrinudi operation, and it permits backward displacement of the foot if desired. Internal fixation with staples[1a] (Fig. 6) or Kirschner wires (Fig. 7) across the denuded surfaces of the articulations maintain the desired position of the foot while plaster is being applied, and it is believed that in many instances more rapid consolidation of the denuded surfaces is brought about by the closer approximation that can be secured by this supplemental fixation. However, such internal fixation has the disadvantage of making it impossible to change the position of the foot, if such is desired, at the first plaster change. A single staple across the calcaneocuboid frequently is necessary to facilitate application of plaster and permits some laxity in repositioning the foot, if necessary. I am convinced that after operation a long leg plaster with the knee flexed adds greatly to the patient's comfort and aids in preventing loss of position of the foot, and a short plaster boot can be substituted 10 to 14 days postoperatively when sutures are removed from the cutaneous incision. If necessary, the position can be corrected at this time—in most instances without anesthetization.

Recurrence after stabilization in paralytic feet has been discussed in considerable detail by Crego and McCarroll,[12] who reviewed 1,100 triple arthrodeses performed at Shriner's Hospital in St. Louis from 1924 through 1937. Recurrent deformities were noted in 212, or approximately 20 per cent



Fig. 6 Modified Hoke arthrodesis. Internal fixation with staples. This is a satisfactory method of fixation, but it has the disadvantage of preventing repositioning of the foot postoperatively.

of the operative cases. Recurrence was due to abnormal muscle pull in 73 per cent of the cases. These were unopposed lateral muscle groups that were left intact, and these authors recommended transplantation of all lateral muscles in the mid-line anteriorly or posteriorly, or resection to remove a possible deforming factor. Associated deformities in the remainder of the extremity accounted for 20 per cent of the recurrences, and were manifested principally by uncorrected tibial torsion, genu valgum or varum, or distal bowing of the tibia and the fibula. Crego and McCarroll emphasized the fact that in stabilization the foot should be placed in correct relationship to the ankle joint without regard for the associated deformity of the remainder of the extremity and that the associated deformity should be corrected subsequently by osteotomy.[12] The remaining 7 per cent of recurrences were due to performance of stabilization on too young a patient or to some cause other than one of the previous factors. Eight years was considered to be the minimal age for stabilization in paralytic feet.

I am convinced, from postoperative observation of approximately 400 patients who had foot stabilizations, that close adherence to the principles laid down by Crego and McCarroll will reduce the number of recurrences to a minimum and prevent many disappointing results. Patterson and associates,[28] in reviewing 305 foot stabilizations, reported 82 per cent successful results based on anatomic and functional principles. Most of the failures were due to undercorrection of the deformity at the time of operation, and the remaining failures were due to performance of the operation at too young an age (younger than 9 years), pseudarthrosis, particularly at the talonavicular joint, muscle imbalance or uncorrected deformities of the remainder of the extremity. Again, Patterson and associates stressed the importance of aligning the stabilized foot with the ankle joint and correcting other deformities of the extremity by subsequent osteotomy. Their

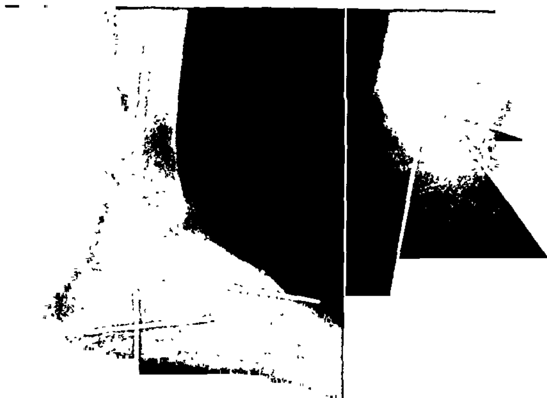


Fig. 7. Modified Hoke arthrodesis. Internal fixation with Kirschner wires.

cases were for other conditions besides paralytic feet, including Friedreich's ataxia, and this may account for some of the failures.

PANARTHRODESIS (PANTALAR ARTHRODESIS)

Panarthrodesis has its greatest usefulness in the paralytic flail foot or calcaneovalgus foot, especially if associated with quadriceps weakness in the thigh. With sufficiently strong musculature around the hip, the stable foot and ankle fixed in slight equinus by this procedure may be rendered brace free. The procedure is also useful after failure of posterior bone block or the Lambrinudi operation, in which no muscle power has been available to transplant anteriorly to assist in dorsiflexion. Conversion to panarthrodesis by stabilizing the ankle will enable these patients to walk *without* a brace. We are using this procedure more and more in the treatment of foot deformities of patients with meningomyelocele and associated spina bifida, since the paralytic pattern frequently involves only extensive motor paralysis below the knee in many cases, and panarthrodesis enables these patients to discard a brace after the bladder difficulty has been corrected. In spite of the sensory deficit always present, we have had little difficulty with postoperative healing or pressure sores in plaster, but one must be doubly cautious in these patients.

Pantalar arthrodesis should be performed in two stages. If the deformity is severe, better correction can be obtained by triple arthrodesis at one stage and ankle fusion at another stage. Moreover, operative trauma and sloughing of the incisional wound have been excessive at times when the procedure was done at one stage. Of the 20 panarthrodeses reported by Patterson and associates,[29] 7 were performed in one stage with severe sloughing in 3 of these, 1 necessitating a pedicle graft to repair the soft-tissue deficit. Ankle fusion can be performed 6 to 8 weeks after the triple arthrodesis, or it can even be delayed until the epiphysial line in the lower tibia has fused; this permits use of a sliding tibial graft without hazarding the epiphysial line.

NAVICULOCUNEIFORM ARTHODESIS

In 1931, Hoke[22] described this operation for correction of extremely relaxed flat feet in children between 11 and 14 years of age in whom lateral radiographs in the standing position revealed a definite sag at the naviculocuneiform joint. He advocated lengthening the Achilles tendon in all children in whom this was shortened structurally. The technic must be performed with precision. The joint between the navicular and the cuneiform bones is exposed through a medial longitudinal incision, and the articular surfaces of the navicular and the medial cuneiform are excised. An assistant holds the foot firmly in the corrected position, and a slot is cut in the navicular and the cuneiform bones across the joint into which is countersunk firmly an accurately cut cortical and cancellous graft secured from the upper third of the tibia. The excised articular space is packed with cancellous bone chips Postoperatively, the foot is immobilized in a well-molded, snug plaster cast, holding the longitudinal arch in full correction. The plaster is worn for a minimum of 12 weeks, and it is necessary to use shoe corrections or longitudinal arch supports for a long period postoperatively.

Butte,[6] in 1937, reported approximately 50 per cent satisfactory results in 76 foot operations by this technic. In 1953, Jack[23] reported satisfactory results in 84 per cent of 46 operations performed between 1946 and 1949 on children between the ages of 11 and 14; many of the cases had been followed for 5 years. He did not perform Achilles tendon lengthening in any patients, and he does not consider this an essential part of the operation Both Butte and Jack stressed the importance of confining the operation to patients in whom the sag could be demonstrated at the naviculocuneiform joint. Crego and Ford,[11] reporting 111 surgical proced-

ures on children with an average age of 12 years, concluded that arthrodesing the talonavicular and the naviculocuneiform joints gave better results than the original Hoke procedure, but the best results were obtained by including the subtalar joint and doing essentially a triple arthrodesis from the medial approach. In my own experience, and that of my predecessor, Dr. Guy Caldwell,[7] the Miller modification of the Hoke procedure has given fairly satisfactory results in limited application. If relaxation and pronation are extreme, and weight-bearing roentgenograms demonstrate talonavicular sag as well as naviculocuneiform sag, subtalar arthrodesis certainly should be added to the procedure to ensure a favorable result. Arthrodesing operations for flat foot never should be performed until all conservative measures have been exhausted, and then they should be reserved only for relief of disabling pain. Arthrodesing procedures never should be done on an adolescent flat foot for cosmetic reasons only, and both parents and patient must be willing to co-operate for a long period postoperatively with use of corrective shoes and supports. Even in its limited applications, results of flat-foot operations of this nature frequently are disappointing because the rigid indications outlined have not been adhered to or co-operation of the patient has not been wholehearted.

ARTHRODESING OPERATIONS WITH SPECIAL INDICATIONS

Tibiotalar arthrodesis, described by Blair[5] in 1943, is reserved for comminuted fractures of the body of the talus or aseptic necrosis of the body after a fracture. Most of these injuries (Fig. 8) seen in World War II were the result of "belly" landings of aircraft. Frequently, these injuries were compound, with the body of the astragalus being extruded posteromedially through the compound wound, and the body was removed at the time of débridement or shortly afterward to prevent skin necrosis. After the compound wound has healed, the remaining viable head and neck of the talus are arthrodesed to the tibia through an anterior approach by sliding a graft from the anterior of the tibia into a



Fig. 8. Tibiotalar arthrodesis (Blair). (*Top*) Compound fracture dislocation of talus. (*Center*) After removal of body of talus at original débridement. (*Bottom*) After arthrodesis of remaining head and neck of talus to tibia by means of sliding bone graft.

slot cut in the remaining talar neck. The upper end of the graft is fixed in the tibia with the ankle in 10° of equinus. The same technic can be used by excising a fragmented or necrotic talar body through the anterior incision without disturbing the head and neck fragment and sliding down an anterior tibial graft in the same manner. The advantages of this procedure over the only alternative—complete talectomy and calcaneotibial fusion—are that the outward appearance of the foot is not changed, backward displacement is not necessary, there is no shortening of the extremity, and the relationship of the foot and the ankle remain reasonably normal with the weight thrust on undisturbed joint tissue. Some flexion-extension of the foot on the leg remains, owing to preservation of the talonavicular joint and the subtalar facets. Our experience with about 12 cases bears out the advantage of the procedure as pointed out by Blair, and I do not believe that this operation has received the application in its rather limited field that it richly deserves.

Extra-articular Subastragalar Arthodesis. Grice,[18] in 1952, described extra-articular arthrodesis of the subastragalar joint, limiting the indications principally to paralytic flat feet, the principal advantage over other procedures being that it can be performed as early as the age of 4 years, and it does not interfere with subsequent growth of the foot.

A short, lateral curvilinear incision is made directly over the subastragalar joint. The sinus tarsus is dissected free of adipose tissue and ligamentous structure, and, with the foot in equinus, the calcaneus is easily placed beneath the astragalus by inverting the foot. A thin layer of cortical bone is removed from the inner surface of the astragalus and the superior surface of the calcaneus, and, through a second incision over the upper portion of the tibia, a piece of cortical bone large enough to provide two grafts is removed with a motor saw. These grafts are countersunk into the sinus tarsus with the foot held in slightly overcorrected position, the grafts being locked by slight eversion of the foot. Stability of the foot can be demonstrated after insertion of the grafts, and a toe-to-groin plaster cast is applied with the foot in maximum dorsiflexion and the knee flexed to 60°. If the equinus of the foot can be corrected at the time of operation, one of the peroneal tendons is transplanted either to the second metatarsal area or beneath the talonavicular joint. If equinus cannot be overcome, then the foot can be wedged postoperatively, and tendon transplantation must be done as a subsequent procedure. In 1955, Grice reported 52 cases in which follow-up had been completed, and there is considerable evidence to indicate that the procedure probably can be used in adult feet with minimal deformity.

SUMMARY

The success of any arthrodesing operation about the foot, as is true of any other joint in the body, depends on certain fundamental principles: (1) selection of a suitable operation to meet the individual case; (2) complete removal of cartilaginous surfaces of involved joints; (3) removal of sufficient bone to correct the deformity; and (4) accurate apposition of the denuded articular surfaces and firm fixation until arthrodesis has taken place. Various types of arthrodesing procedures about the foot, and their indications have been discussed The particular technic for the operative procedure that in my experience has resulted in the greatest number of successful outcomes with the fewest complications has been outlined briefly.

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Arthrodese del Pede

Summario in Interlingua

Le indicationes pro arthrodese del articulationes talar e tarsal pote esser summarisate in terminos general como (1) imbalancia muscular post paralyse o vulneration del musculos que determina le movimentos del pede e talo e (2) movimento dolorose in consequentia de irreparabile lesiones articular e deformitates ossee, tanto congenite

como etiam acquirite. Le successo de omne *operation arthrodetic in le pede*—precisemente como in altere articulationes del corpore—depende de certe principios fundamental. Istos require (1) le selection del appropriate operation pro le caso individual, (2) le elimination complete del superficies cartilaginose del articulationes in question, (3) le ablation de un sufficiente quantitate *de osso pro corriger le deformitate, e (4)* le accurate approximation del disnudate superficies articular e le firme fixation de illos usque le arthrodese se ha effectuate.

In casos de sever deformitate, le correction preliminari del deformitate de tissu molle—per suppression in un apparato de gypso o per section chirurgic del constric*tion in le tissu molle—reduce le grado del* resection ossee que es requirite al tempore del arthrodese. In conditiones paralytic, arthrodese debe generalmente preceder omne transplantation de tendine. Proque stabilitate es essential in un articulation que debe supportar pesos, transplantation de tendine sol es rarmente satis.

In *patientes pediatric, arthrodese* de pede es rarmente indicate ante le etate d octo *annos*. Essayos d effectuar lo a etates troppo precoce ha essite un causa frequente de malsuccesso e de recurrentia del deformitate.

Le operationes arthrodetic in le articulationes del pede pote esser classificate in cinque gruppos:

1. Arthrodese tibiotalar (fusion al talo).
2. Arthrodese triplice (talocalcanee, talo*navicular, e calcaneocuboide*).
3. Arthrodese pan-talar, i e. pan-arthrodese (tibiotalar, talonavicular, talocalcanee, e calcaneocuboide).
4. Arthrodese naviculo-cuneiforme (operation de pede plan).
5. Operationes arthrodetic con indicationes special:
    a. *Arthrodese tibiotalar de Blair.*
    b. Arthrodese extra-articular del articulation subastragalar secundo Grice.

Es describite le specific indicationes, technicas, e complicationes de iste varie manovras, e etiam le disveloppamento historic del varie operationes arthrodetic in le articulationes del pede.

17

Soft-Tissue Releasing Procedure for Persisting Heel Varus in the Uncorrected Club Foot

WEBSTER B. GELMAN, M.D.*

The problem of persisting deformities of the club foot after conservative treatment has been given considerable study for many decades. There is no question that, despite institution of early and vigorous conservative treatment, in a variable percentage of cases deformities persist. Kite[12] reported 92 per cent corrected by conservative treatment; Smith,[16] 81.8 per cent by the same means. The deformity varies both in degree and in location. Occasionally only one site is involved. Usually there are several, but not infrequently all major components of the club foot persist. These major deformities can be grouped into the following categories: tibial torsion, equinus, cavus, forefoot adduction (varus) and heel varus.

One of the earliest and most stimulating papers dealing with soft-tissue surgery of this type was written by Codivilla.[3] He expounded on the need, in his clinic, for surgery as an expediency for correction, and in essence this surgery was a total release of all contracted soft tissue on the medial aspect of the foot. Although this work was an outstanding contribution to the club-foot problem, it never received the attention that it warranted. His preference for soft-tissue releasing surgery instead of prolonged conservative treatment was quite apparent. The operations of Ober[15] and Elmslie[6] pursued the same end as the Brockman[1] operation; i.e., the correction of inversion due to soft-tissue contracture. Elmslie added the osteotomy of the neck of the talus and distal portion of the os calcis to the soft-tissue release. Ober also corrected the equinus by sectioning the Achilles tendon at the time that he performed a medial stripping. Cobb,[2] in his review of the Brockman operations performed at the State University of Iowa, indicated the shortcomings of this operative approach.

All the above writers contributed to the author's enlightenment, but none as much as McCauley,[13,14] whose medial release procedure was felt to be the soundest. Wagner and Butterfield[19] describe a procedure that appears to be somewhat excessive, in that a portion of the tibialis posticus is discarded, and the inferior calcaneoscaphoid ligament is sectioned.

Garceau[9] stimulated the wide-scale introduction of the tendon transposition as a means of correcting the club foot. Other significant contributions of this aspect of the approach were made more recently by Farill[7] and Fried.[8] Critchley and Taylor,[5] in 1942, made a worth-while criticism of the tendon transplantation and placed its indication on a sounder basis. They said that the transplantation of the tibialis anticus to the lateral portion of the foot, as a means of *maintaining* correction in a foot in which the muscle

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imbalance indicated that recurrence of the deformity was anticipated or had recurred, was a sound procedure, but they were inclined to contest the corrective power of the transplanted tendon when fixed and rigid deformities existed.

The emphasis at this clinic for the past 10 years has been on the study of the soft-tissue release of persisting club-foot deformities. A procedure necessary for the release of each component of the deformity has been established, but, because of the extensive nature of the work, only the material for the release of the heel varus will be discussed here. It should be assumed that this type of operation is not proposed as a procedure to replace tendon transposition or conservative treatment; it is solely to correct a specific soft-tissue contracture that persists despite conservative measures. The corrected foot may also require correction of muscle imbalance by tendon transposition at a later date.

The basic purpose of the operation is to perform a complete release of the medial aspect of the hind foot, creating a correction of the distorted relationship between the os calcis and the talus. It is simply the freeing of the os calcis at the subtalar joint so that the heel can be placed in a neutral or slightly overcorrected position. A forefoot or equinus deformity is not affected. It was demonstrated to us in our early cases (Fig. 1) that an overcorrection was easily possible if certain steps mentioned by previous authors were adhered to. The manner by which complications can be avoided are discussed in the following paragraphs in regard to the surgical technic.

The incision (Fig. 2a), which can be extended at either end for additional surgery, is made on the medial aspect of the foot and extends from a point anterior to the tendon of Achilles distally to the medial cuneiform. The concavity faces cephalad, and the lowest portion passes below the level of the sustentaculum tali.

The margins of the wound are dissected subcutaneously, exposing as large an area as the incision will permit (Fig. 2b). In the lower portion of the wound, one notes the fibers of the abductor hallucis muscle, and posteriorly this structure envelops the neurovascular bundle. The abductor hallucis fibers then are dissected carefully from the underlying deep structures, as well as the neurovascular bundle (Fig. 2c). If the plantar fascia is tight, it may be severed at this stage of the procedure.[17]

The sheaths of the tibialis posticus tendon and the flexor digitorum communis tendon are opened as extensively as the exposure will permit (Fig. 2d). The external appear-



FIG. 1. Marked overcorrection of heel varus. In this case the plantar calcaneonavicular ligament was cut, and the tibialis posterior was lengthened. The standing roentgenogram shows a vertical talus.

ance of the tendon sheaths blends so well with the deep fascial structures that the relationship of these tendons to the medial malleolus should be used as a guide for their exposure. This is particularly helpful in a very young child or in the foot having an extreme degree of heel varus.

The tibialis posticus tendon is severed by

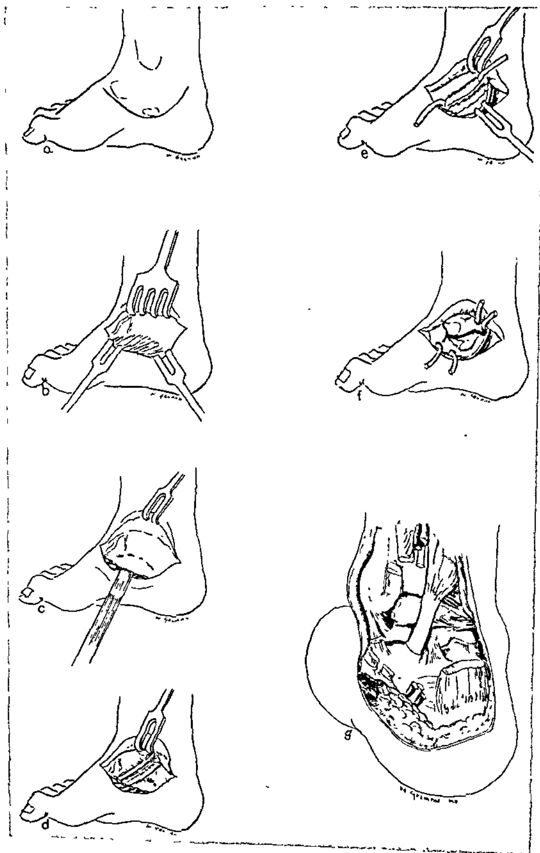


FIG. 2. See text.

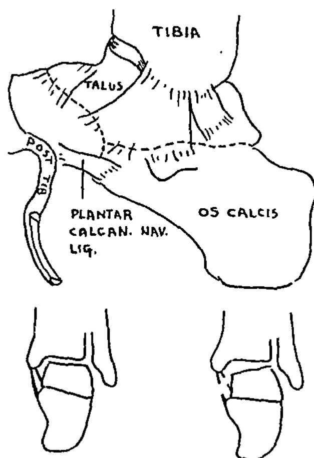


FIG 3. The broken line shows the location of the incision of the ligaments and the capsule to release the medial aspect of the subtalar joint (*Bottom, left*) Posterior view of the area. (*Bottom, right*) A tilt of the talus in the ankle mortise occurs if the incision is too close to the tip of the medial malleolus. The plantar calcaneonavicular ligament is left intact.

means of a Z-incision (Fig. 2e), and the distal portion then is freed to its peripheral attachment on the navicular in order to expose the deep and somewhat obscure talonavicular articulation. The flexor digitorum communis then is lifted from its sheath and retracted posteriorly, carrying with it and protecting the neurovascular bundle. The medial aspect of the subtalar joint now is exposed.

There are four important points in the release of the contracted capsule and ligamentous structures joining the astragalus and the os calcis.

1. The integrity of the ankle mortise must be maintained, for, if it is not, correction of the heel varus will be incomplete, and most of the correction will occur at the ankle joint (Fig. 3). To prevent this, the deep portion of the deltoid ligament, the talotibial ligament, must not be severed. The calcaneotibial ligament must be severed. The incision of the capsule and the ligament, therefore, must hug the sustentaculum tali to avoid this error.

2. The strong plantar portion of the calcaneonavicular ligament (spring ligament) must be left intact (Fig. 3). If it is severed, a rocker bottom deformity may result (see Fig. 1).

In the early cases, following the suggestions of previous authors, this ligament was severed, and, as a result, two overcorrections did occur. In these instances the talus became vertical, due to the absence of this essential supporting structure. When the ligament is left intact, it in no way prevents adequate correction of the heel varus, provided that the following steps are added to the above procedure.

3. The distal sections of the medial aspect of the subtalar joint or what Parker[5] called "the astragaloscaphoid capsule" is a markedly thickened structure binding the medial *malleolus, sustentaculum tali and the tubercle* of the scaphoid together. The incision through this area (Fig. 3) must be deep enough to expose completely the medial and the dorsomedial aspect of the talonavicular articulation. The tibialis posticus passes over this mass, but it can be freed easily. Lengthening this tendon does not permit correction of the heel varus to the degree that opening the subtalar joint does. In many cases, especially in the older age group, no improvement was noted when the tendon was lengthened.

4 The most difficult step of the procedure is freeing the medial portion of the posterior aspect of the subtalar articulation (*Fig. 2g*). *Among the authors mentioned* above, with the exception of Codivilla and McCauley, nothing is said about this portion of the subtalar release, and perhaps this

accounts in part for some of the poor results of soft-tissue surgery. The study of the anatomy of the posteromedial aspect of the subtalar joint indicates that the tendon of the flexor hallucis longus is held firmly in an osseous-fibrous canal that bridges the subtalar joint. In addition, the posterior calcaneotalar ligament is also involved in the deformity. The tendon of the flexor hallucis longus must be freed from its canal by a vertical incision of the sheath and retracted posteriorly. This will expose all the posteromedial structures and permit an incision into the joint from without. It has been noted many times in performing this operation that, unless this part of the procedure is performed adequately, complete correction of the posterior varus usually is impossible. The os calcis, instead of pronating, abducts.

To complete the freeing of the os calcis, additional structures must be incised. These are the dorsal talonavicular ligament and the interosseous talocalcaneal ligament. The latter can be done blindly with a pointed knife. The os calcis then can be placed quite easily in slight valgus. The only structure that is sutured, except for the subcutaneous tissue and skin, is the tibialis posticus. At first it was felt that considerable lengthening of this tendon was necessary, but it was found that, particularly in the younger age groups, it was not necessary to lengthen this tendon at all, and, in the older age groups, only to a slight degree. Heyman,[10] who has had considerable experience with soft-tissue releasing surgery for the club foot, is in complete agreement. The flexor digitorum communis and the flexor hallucis longus tendons never are lengthened, for they do not interfere with the correction.

There have been no problems of any consequence with wound healing; nor has it been found necessary to correct the deformity only partially and wait for the foot to accommodate to its new position and subsequently increase the correction. The leg is immobilized for 2 to 3 months in a cast with the knee included.

The limitations of an operation of this type probably are self-evident. Age would play a dominant role in the end-results. The cases from 4 to 10 years of age naturally are more resistant, because by this time the bone deformation can block complete correction. In our cases only 1 patient was over 3: she was 6, and 1 foot was a failure. However, one should not necessarily discard a procedure of this type in this age group, because there is very little else available until the age of 10 or 11 other than the tendon transplant. The operation should simply be placed in its proper niche; that is, one that in the older age group will improve the alignment of the foot, permitting increased activity of the patient and growth of the foot until the child is old enough to have an arthrodesing procedure performed. In the first year of life this operation probably has little place, because until then conservative treatment has not been exhausted. In addition, the operation is difficult technically. In this early age group, one should probably heed the advice of Stewart[18] and remove the effect of positive deforming forces. As he has suggested, the early division of the medial portion of the Achilles tendon and its transfer laterally (or the subcutaneous tenotomy) (Fig. 4) have yielded excellent results in many of our cases and have been of great help in eliminating the resistant inverted foot in the infant. The implication by some that early minor corrective surgery is radical and that prolonged immobilization in plaster is conservative is open to question on the basis of Stewart's and Codivilla's contributions.

Without the adequate evertor power present, the correction that one obtains by soft-tissue releasing operations is difficult to maintain without transplantation of the tendon. It is definitely felt to be hazardous to transplant a tendon at the same time that the soft-tissue release operation is being performed, except possibly in older children with rigid deformities. Cases of arthrogryposis with club-foot deformities have been ex-



FIG 4. Bilateral subcutaneous tenotomy of tendon of Achilles performed at 3 months of age in a rigid club foot. Follow-up at 2 years showed normal function and excellent correction.



FIG. 6. Same case (bilateral) as that in Figure 1. Overcorrection with poor result *on left, right foot corrected, at 9-year* follow-up. Arthrodesis performed in attempt to correct severe overcorrection.

cluded from this series because the deformities are so severe and, in general, soft-tissue surgery on these feet has been extremely discouraging. *Milder cases may be helped,* but generally the arthrodesing procedures are required for plantigrade ambulation.

RESULTS

Fifteen cases are available for study. The average age at the time of surgery was 34 months. The average follow-up was 5.9 years. Eleven of the results were considered to be satisfactory, in that the heel could be maintained in a neutral or slight valgus position (Fig. 5). Four of the 15 cases were unsuccessful. Two of these were rated as poor because overcorrection was obtained (*Fig. 6*). *One of the other poor results was* in a 6-year-old girl who was the oldest case in the series and previously had had a Brockman operation.

This must be regarded as a preliminary review, even though Compere[4] suggests a 5-year follow-up as being adequate. It



FIG. 5. Bilateral case. Right foot considered to be successful. Left foot, unsuccessful; overcorrection present at 7-year follow-up.

would be much more reassuring to have a larger series of cases with a minimum of a 10-year follow-up.

It is within the realm of possibility, when one fails in the conservative treatment and does not delay too long in favor of the surgical indications, to obtain an extremely high percentage of good results by soft-tissue procedures. Naturally, other components of the deformity may need correction. Heyman's[11] procedure for correction of the forefoot, heel-cord lengthening and posterior capsulotomy for the equinus plus tendon transplantation for the potential evertor weakness are all sound procedures of proven merit. Perhaps on the basis of this report, which substantiates McCauley's conclusions, the heel varus release can also be added to the list.

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Experientias in le Uso de un Technica de Relaxation de Histos Molle in le Tractamento de Persistente Talon Var in Casos de Talipede Non Corrigite

Summario in Interlingua

Le tractamento chirurgic del non-corrigite talipede es un difficile problema, e in recente annos grande attention ha essite prestate a technicas de relaxation de histos molle. Le presente articulo se occupa del correction de persistente talon var e summarisa un studio de dece annos. Le technica chirurgic es tractate in detalio, e su limitationes es discutite. In un alte procentage de casos seligite il es possibile obtener un satisfacentissime grado de correction.

18

The So-Called Tight Heel Cord

STANLEY S. TANZ, M.D.*

It is commonly believed that a tight heel cord may be the cause of a disabling pronated flat foot. The tight heel cord is demonstrated by inverting the foot to lock the subastragalar joint, extending the knee to tighten the gastrocnemius and then seeing how far the foot can be dorsiflexed. According to some, the normal ankle should dorsiflex to a right angle; to others,[4,6,8,10] to 10° further. Stretching exercises with the feet inverted and, if these are ineffective, surgery ranging from heel cord lengthening[6,10,13] to fusions[8] have been recommended.

* Tucson, Ariz

Two hundred normal subjects with no foot symptoms have been examined to ascertain the normal degree of heel cord tightness, and the ankle joints of several cadavers have been investigated.

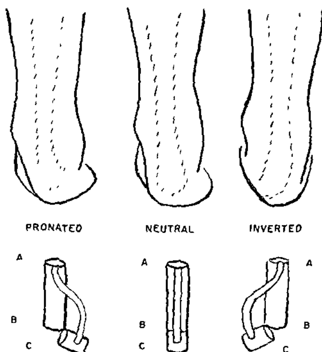


FIG 1. Theoretic effect of heel rotation on heel-cord tension Heel cord AC should be most relaxed in pronation and in inversion and tightest in neutral position, since one side of a triangle is shorter than the sum of the lengths of the other two sides. Two cylinders connected by a strap illustrate the anticipated effect of heel rotation on heel-cord tension.

CLINICAL AND ANATOMIC OBSERVATIONS

In normal subjects, with the foot inverted maximally and the knee extended, ankle dorsiflexion usually was found to be blocked at about 10° less than a right angle (Fig. 2), while, with the foot in neutral position, the dorsiflexion range was much greater in infants but after the age of 4 or 5 usually was blocked at 90°. (An average of 90° means that some ankles dorsiflexed 10° more and some ankles 10° less than this.) There were large individual variations not related to the subject's sex or activity but due presumably to variations in the structure of bones and ligaments [8] Closely knit joints with limited dorsiflexion were not unusual; generally they were found in feet with neither pronation nor flattening of the arches and neither limited athletic ability nor endurance, and they did not cause leg or foot discomfort (Fig. 6).

The following observations indicate that whatever blocked the dorsiflexion of the inverted foot, it was not tightening of the heel cord However, they indicate also that, with the foot in a neutral position, heel cord

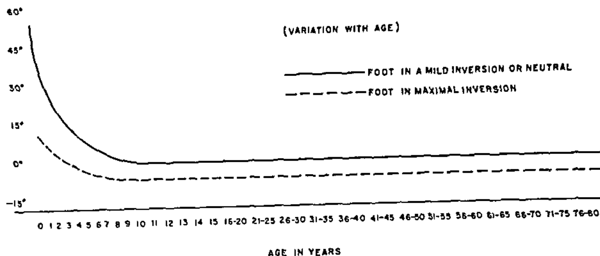


FIG. 2. Variation of dorsiflexion range of ankle with age.

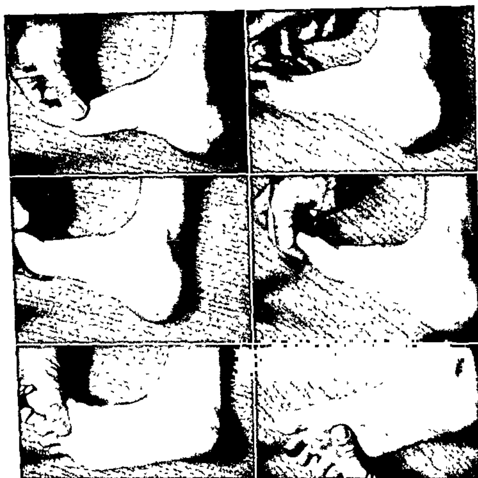


FIG. 3. Knee flexion increases dorsiflexion range if foot is everted or neutral, but not if inverted maximally. (*Top, left*) Maximal ankle dorsiflexion with foot everted, knee extended. (*Top, right*) Maximal ankle dorsiflexion with foot everted, knee flexed. (*Center, left*) Maximal ankle dorsiflexion with foot neutral, knee extended. (*Center, right*) Maximal ankle dorsiflexion with foot neutral, knee flexed. (*Bottom, left*) Maximal ankle dorsiflexion with foot inverted, knee extended (*Bottom, right*) Maximal ankle dorsiflexion with foot inverted, knee flexed.

tightening was only one factor in blocking dorsiflexion:

1. When the knee is extended, the foot strongly inverted and the ankle dorsiflexed passively as far as possible, discomfort is noted over the posterolateral aspect of the ankle; and, if the heel cord is palpated, it will not be found to be tightened. The same motion with the *foot in neutral position* causes discomfort in the calf and considerable tightening of the heel cord.

2. Under general anesthesia, with the triceps surae relaxed, the foot in maximal inversion shows no increase in dorsiflexion range, whereas, with the foot in neutral position, marked increase of dorsiflexion range occurs under anesthesia.

3. If the foot is in maximal inversion, flexing the knee to relax the gastrocnemius does not increase the range of ankle dorsiflexion, whereas, if the foot is in neutral position or everted, flexing the knee does increase ankle dorsiflexion range (Fig. 3).

4. In the cadaver, with the foot in neutral position and in maximal dorsiflexion (Fig. 5A-E), sectioning the heel cord causes the heel cord ends to gape and the dorsiflexion range to increase. However, *with the foot in maximal inversion, there* is no separation of the tendon ends and no *increase in dorsiflexion range after sectioning* the tendo achillis.

These observations all clearly indicate that dorsiflexion with the foot in inversion is not limited by tightening of the heel cord. The foot is said to pronate in order to relax the tight heel cord, but a moment's reflection shows that inversion should relax the heel cord as much as eversion does (Fig. 1). Even the newborn infant with a relaxed heel cord that allows marked dorsiflexion with the foot neutral and with the knee extended (Fig. 4), shows limitation of dorsiflexion at about a right angle when the foot is inverted markedly.

Cutting the transverse and the posterior talofibular ligaments of the ankle (Fig. 5F) did not increase the dorsiflexion range with the foot inverted maximally, but cutting the calcaneofibular, the anterior talofibular and the posterior deltoid ligaments in addition did increase the range, although this made the ankle grossly unstable.

The checking of motion by the twisting of ligaments, which causes compression of articular surfaces, has been described as "torsional impaction" in the ankle[1] and also in the shoulder,[12] the craniovertebral joints,[13] *the carpometacarpal joint of the thumb,*[5] *the* hip,[9] etc. Experiments with amputated limbs



Fig 4 In the newborn, with the foot in neutral position dorsiflexion is possible to where the foot almost touches the leg, while, with the foot in extreme inversion, maximal dorsiflexion is only a few degrees beyond a right angle. (*Left*) Dorsiflexion with foot neutral (*Right*) Dorsiflexion with foot in maximal inversion.



FIG. 5. Cadaver experiments. With heel cord sectioned, with foot neutral, ankle dorsiflexion is increased markedly and causes separation of tendon ends, while, with foot in maximal inversion, dorsiflexion is not increased, and tendon ends do not separate. Sectioning the transverse and the posterior talofibular ligaments does not increase dorsiflexion range.

(A, *top, left*) Maximal dorsiflexion of cadaver foot. (B, *top, right*, and C, *center, left*) Following section of heel cord, with the foot neutral, increased dorsiflexion is possible with separation of tendon ends. (D, *center, right*, and E, *bottom, left*) Following section of heel cord, with the foot inverted maximally, increased dorsiflexion is not possible, and there is no separation of tendon ends. (F, *bottom, right*) Section of transverse and posterior talofibular ligaments did not increase dorsiflexion with foot inverted maximally.



FIG. 6. Athletic 11-year-old child with "tight heel cord" but no foot symptoms (*Left*) Dorsiflexion with foot neutral. (*Center*) Dorsiflexion with foot inverted. (*Right*) Normal arch and no pronation.

have shown that the structures that limit dorsiflexion of the inverted foot are the bones and the ligaments.[1]

CONCLUSIONS

1. Dorsiflexion range of the foot held in marked inversion does not test heel cord tightness, which it is supposed to do.

2. The dorsiflexion range of the foot in neutral position with the knee extended is a measure of heel cord tightness or of structural variations of bones or ligaments.

3. In normal subjects, there is a marked individual variation in the range of passive ankle dorsiflexion. The range is much greater until the age of 4 or 5 years than afterward.

4. If the knee is extended, the foot held in neutral position may be limited in dorsiflexion at short of a right angle and yet not be pronated, flat or symptomatic.

5. "Stretching the heel cord," as usually performed, puts a stretch on the lateral ligaments of the ankle and pressure on the articular surfaces of the ankle joint but does not stretch the tendo achillis.

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Le Si-Appellate Tense Tendine Calcanee

Summario in Interlingua

Le si-appellate tense tendine calcanee es extensemente considerate como un causa de symptomas in le pede e del deformitates de pedes plan. Le methodo usate in determinar le presentia o absentia de tense tendines calcanee—i.e., mesurar le grado possibile de dorsiflexion del pede in position de inversion maximal con le genu extendite—non revela realmente le grado de tensitate del tendine calcanee sed plus tosto le variationes structural in le ligamentos e ossos circum le articulation talocrural.

Dorsiflexion con le pede in position neutre—sin inversion, sin eversion—permitte, il es ver, le mesuration del grado de tensitate in le tendine calcanee, sed iste valor varia con le etate del patiente, essente considerabilemente plus que 90 grados in subjectos de minus que quatro annos. Mesmo si le test del dorsiflexion con le pede in position neutral revela le presentia de un tense tendine calcanee, iste constatation es usualmente sin significative importantia clinic. Le base de iste conclusiones es un serie de studios in subjectos normal e in cadaveres.

19

Jones's Fracture: Fracture of Base of Fifth Metatarsal*

I. M. STEWART, M.B., FR.C.S.E.†

Jones's, or dancers', fracture is a common injury. Contemporary fracture textbooks offer conflicting advice on treatment and prognosis. A study of 51 consecutive cases occurring in a year is reported and suggests a classification on which treatment, and subsequently prognosis, can be based.

HISTORY

The literature on Jones's fracture is small; its eponymous title takes origin from a famous sufferer (Jones, 1902[8]). In the years following, a few records appeared of similar cases (Graham, 1906;[5] Wharton, 1908;[20] Young, 1908[22]). In conformance with the apparent minor nature of the lesion, it receives brief mention in standard textbooks (Key, 1937;[10] Wilson, 1938;[21] Howorth, 1952;[6] Watson-Jones, 1955;[19] Böhler, 1958[1]).

Initial interest in metatarsal fractures was later directed to the more controversial "march foot" syndrome. Between the world wars, attention to such injuries related mainly to the considerable toll of morbidity from direct injury fractures in industry (Carp, 1927;[2] Irwin, 1938;[7] Morissey, 1946[12]).

PROGNOSIS

Despite the commonly believed innocent nature of the injury, there is cause for caution. Patients have been encountered whose symptoms were either severe or persistent. One patient in this series attended for 11 months before becoming symptom free. Various authors include a guarding clause in referring to prognosis.

Perkins (1958)[15] states that "if the foot is put in plaster it remains painful for months." This may be an indictment of plaster that should correctly be leveled at a particular fracture type. Bohler draws attention to the unusual behavior of metatarsals as regards production of callus. It is stated that the avulsion fracture of the base of the fifth metatarsal takes 10 to 12 months to unite by bone. Patients described by him suggest that some symptoms at least may persist until union occurs. Whilst the primary prescription by Böhler and Watson-Jones is for strapping, the latter concedes that plaster of Paris may be required. "This fracture does not require immobilization in a plaster cast" (McKeever, 1950[11]). "Failure to detect even a small crack in a metatarsal may be responsible for several months' difficult walking" (Irwin, 1938[7]).

In the practice of military surgery by members of this unit in World War II there were instances in which bone-grafting was

* This study was made while the author was holding a Clinical Research Fellowship of the Scottish Hospitals Endowment Research Trust. He is grateful to Mr I. S. Smillie, lecturer in charge, Department of Orthopaedic Surgery, Queen's College, St. Andrews University, and to the other surgeons of the Regional Fracture and Orthopaedic Service for both their interest in the work and their permission to study their patients

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needed to secure union of some fractures of the base of the fifth metatarsal. However, it may have been that extreme activity had been imposed on an injury that would have secured more adequate rest in less arduous circumstances. The resort to bone-grafting for the injury is also referred to by Morrison (1937).[13]

It is clear that, whereas the eventual prognosis does not necessarily imply a chronic disability, the immediate prognosis may show considerable variation in duration and in severity of symptoms.

ANATOMY

A. *Structures attached to base of fifth* metatarsal: 1. Joint capsule. (Jones remarks the very firm attachments of the fifth metatarsocuboid joint. "So powerful are these ligaments that dislocation of the base is the rarest of accidents. It is obviously easier to break the bone than to dislocate it.") 2. Calcaneometatarsal band of plantar fascia. 3. Peroneus brevis. 4. Peroneus tertius. 5. Flexor digiti minimi. 6. Abductor digiti minimi. 7. Interosseous muscles.

B. The arrangement in which the fourth and the fifth metatarsals share the cuboid articulation is relevant, as is also the shape of this joint. The facets on the cuboid for the fourth and the fifth metatarsals may appear as part of a continuous curve or may be separated by a distinct angle. A shearing force from this angle could readily be assumed to act on the metatarsal in reaction to a thrust on the lateral border of the foot.

The amount whereby the styloid process overhangs the joint proximally appears to vary and invite isolated fracture when relatively long. So irregular is the shape of this bone, however, that a small alteration in radiographic projection can produce a considerable variation in the shape of its outline. A difference in radiographic projection similarly demonstrated comminution clearly in an anteroposterior view (Fig. 1), whereas the oblique film was less revealing on the same occasion (Fig. 6).

In common with other fractures from indirect violence, the pattern of skeletal failure is related to local variations in configuration and bone structure. Further reference is made to this in considering the mechanism of injury.

MECHANISM OF INJURY

Fracture of the base of the fifth metatarsal is commonly the result of a sudden thrust, usually from the ground, against the lateral border of the foot while the heel is raised. Alighting from public transport was a common source of injury; country dancing, although popular locally, was not mentioned in this series.

In the clinical examination of a recent case, search was made for abnormal mobility, and the shaft of the bone showed the abnormal movement; the base of the metatarsal remained firm. This observation has implications for treatment; it also confirms the suggestion by Jones that the fracturing force may expend itself on the metatarsal shaft. In addition, it would confirm the observations of Jones, Christopher (1923,[3]



FIG. 1. Fracture base of fifth metatarsal, same case and time as Figure 6, anteroposterior view.



FIG. 2. Direct trauma fractures. (*Left*) "Run-over" injury. (*Right*) Compound inversion injury from conveyor.

1940[4]) and others on the strong anatomic attachments of the base of the fifth metatarsal.

Much of the early discussion on fracture of the fifth metatarsal relates to the parts played by direct or indirect violence. Before Jones's paper, metatarsal fractures were all considered to be the result of direct trauma; those which were of such origin were at least more likely to be noticed. Once the part of indirect trauma was suggested, the discussion changed to the relative importance of avulsion by strong contraction of the peroneus brevis (Böhler) or by forced inversion (Watson-Jones). A direct blow and muscle pull are both mentioned by Rider (1937).[16]

These discussions are of no more than academic interest unless they have some bearing on prognosis or treatment In some instances the comminuted nature of the fracture suggests direct trauma. Even in his description of the indirect injury. Sir Robert Jones speaks of "a cross breaking strain directed anteriorly to the metatarsal base" —a rather direct type of force. The importance of the mechanism of injury lies in the way in which the fracturing force does expend itself. It may be the expenditure on the shaft of the fifth metatarsal that determines the occasional abnormal mobility of the distal fragment.

The anatomic determination of the path taken in the expenditure of an indirect force was evidenced in another way. Two patients in this series sustained bilateral fractures from separate injuries at about a year's interval. In both instances there was exact symmetry between the fractures sustained. Such an observation has been made before (Stewart, 1957[18]). The symmetry of fractures from indirect violence indicates the

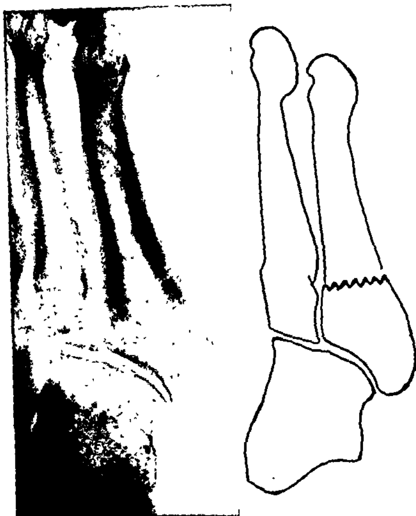


FIG. 3. Jones's fracture at junction of shaft and base of fifth metatarsal.

importance of local bone shape and strength in determining the effects of indirect trauma (Paget, 1901[14]).

Three fractures in this series were found not to conform to the common patterns. All three were due to gross direct trauma. One case resulted from a "run-over" injury (Fig. 2, *left*). In another, a compound fracture of the base of the fifth metatarsal occurred when a workman's foot was caught in the wooden slats of a conveyor (Fig. 2, *right*). The foot was inverted, the base of the fifth metatarsal was avulsed, but the peroneus brevis insertion appeared at operation to have intact bands that continued over the fracture site. However, the bizarre effects of a particular direct injury cannot be excluded in this instance. Nonetheless, the three exceptions tend to prove the rule regarding the fracture patterns from indirect inversion injuries.

Stress fracture in this region has also been recorded. The case reported by Graham[5] appears to have been one. The same author refers to the recognition by Whitman of the possibility of this fracture in the absence of noticeable acute trauma.

Therefore, a classification that is relevant to treatment is suggested on the basis of the anatomic types of fracture and in the light of the common relationship of such fracture patterns to their causative forces.

CLASSIFICATION

The textbooks mentioned do not attempt to classify the fracture other than in Böhler's reference to the size of the fragment avulsed, styloid process or "entire base."

The cases illustrated in Jones's papers showed fractures that were "three-fourths of an inch" distal to the tip of the styloid process. These fractures occur at the junction of shaft and base and correspond approximately in level to the distal limit of the joint

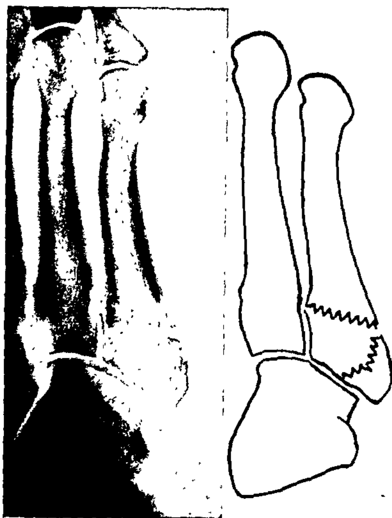


FIG. 4. Jones's fracture with comminution.

between the fourth and the fifth metatarsals. This point of contact is the fulcrum about which "the body weight expends itself on the fifth metatarsal, rotating it slightly inward" (Jones), the base being fixed. Such a fracture is illustrated in Figure 3. The capsule of the fifth metatarsocuboid joint would escape being torn in such a fracture, as would be expected from its anatomic strength as noted. This injury may correspond to the "avulsion of the entire base" mentioned by Böhler.

A further degree of bone damage in this injury from "indirect" violence is seen in instances in which a fracture at the level described is accompanied by comminution of the base (Figs. 4 & 1). The obvious explanation is that the base is crushed secondarily between the shoe and the cuboid and the fourth metatarsal. This could occur following solution in continuity of the lateral border of the foot on the initial fracture at the junction of shaft and base. In this type of injury the greater degree of bone damage has a bearing on treatment.

In other cases the fracture occurs at a more proximal level. The appearances then are those which have given rise to the descriptions of avulsion of the base by muscular action or by other structures tightened by inversion of the foot when the heel is raised (Fig. 5). In this group also there is some need for subdivision. There are anatomic factors that are relevant to treatment. Involvement (Fig. 6) or escape of the articular surface offers at least theoretic reasons why the prognosis may differ in the two circumstances. The desirability of articular reconstruction with a large fragment suggests the need for open repair such as would

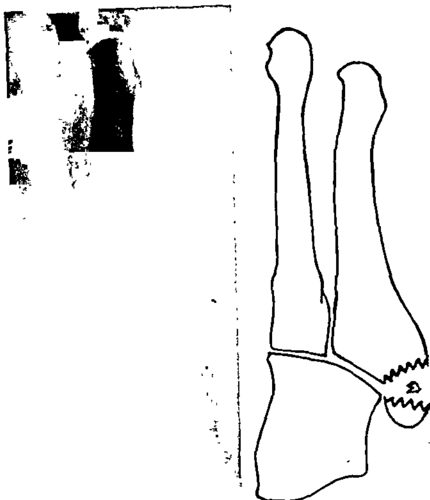


FIG. 5. Avulsion fracture of styloid process of fifth metatarsal.

be less obviously necessary to prevent distraction of the peroneus brevis insertion alone. There are no radiographic signs to confirm the clinical diagnosis of strain of the epiphysis of the fifth metatarsal base other than the actual demonstration of its presence. This injury (Fig. 7) could be classified with the cases of simple avulsion of the styloid process.

Study of the present series of fractures indicates that they may be grouped in the classification shown in the table on page 196. This classification does not seek to complicate the clinical problem but rather to show how fractures as different as those illustrated (Figs. 1 & 5) may nonetheless be expressions of similar accidents though greatly differing in anatomic lesion. On the other hand, although a single etiologic grouping thus is possible, it is at the same time worth considering the various lesions separately as regards treatment. As previously mentioned, abnormal mobility may occur in the distal or in the proximal fragment. Admittedly, fractures do occur at intermediate levels, but in this series it has not been found difficult to allocate them to one or other main group. The extreme case is no less worth instancing to illustrate the principles involved.

TREATMENT

Traditional methods of treatment were used in most cases. These included simple recommendations regarding supporting footwear or the use of strapping with or without padding round the tender prominence. Plaster was used 10 times. One case was treated by open reduction and internal fixation with the nail-gun (Smillie, 1957[17]). At the cost





FIG. 6 (*Left & Center*). Avulsion fracture involving fifth metatarso-cuboid joint.



FIG. 7. Epiphysis of base of fifth metatarsal in a case of epiphysial strain.

of the period of confinement to bed, a result was obtained that was as satisfactory as the radiographic appearances (Fig. 8). It is suggested that more fractures could be treated similarly when the indications are reviewed in terms of the suggested classification.

The treatment of these fractures has largely been symptomatic. It is probably correct to say that treatment should continue to be guided by this feature, and severe initial symptoms can reasonably be assumed to be an index not only of the bony and soft-tissue damage but also of the prognosis However, the classification described is aimed at emphasizing the relevant factors when more radical treatment is contemplated Nonetheless, it is difficult to see the need for treatment so radical as that described by Young (1908).[22] Persistent symptoms on that occasion were treated by excision of the distal fragment and later still by excision of the distal end of the fourth metatarsal as well.

Two indications for operation merit consideration. Firstly, fractures at the junction of shaft and base can be stabilized when there is abnormal mobility, comminution of

CLASSIFICATION AND INCIDENCE OF FRACTURES OF BASE OF FIFTH METATARSAL (51 CASES*)

	CASES
1. Fracture at the junction of shaft and base (Jones) (Fig 3)	8
Comminuted (Fig. 4)	6
2 Fracture of the styloid process (Fig. 5)	11
With joint involvement (Fig. 6)......	21

*Radiographs untraced, 2, Direct trauma fractures 3.



Fig. 8. (*Left*) Fracture involving joint. (*Right*) After open reduction and internal fixation.

the base requiring to be excluded. Secondly, the fifth metatarsocuboid joint can be reconstructed when there has been an "avulsion" fracture with a larger sized fragment (Fig. 6).

The need to ensure safe positioning and healing of a scar near a bony prominence on the foot should require no emphasis other than its mention.

The comminuted type of fracture may be an indication of damage of sufficient severity to merit the more complete immobilization afforded by plaster. The amount of abnormal mobility of the shaft would certainly appear to be a relevant finding in this decision.

SUMMARY

1. A study is reported of 51 cases of fracture of the base of the fifth metatarsal seen consecutively in the Eastern Region (Scotland) Fracture and Orthopaedic Service during 1 year.

2. A classification is recommended as a guide to interpretation and treatment.

3. The prognosis and the treatment are discussed in terms of the classifications suggested.

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Fractura de Jones: Fractura del Base del Quinte Osso Metatarsal

Summario in Interlingua

Es reportate un studio de cinquanta-un consecutive casos de fractura del base del quinte osso metatarsal. Le studio esseva interprendite pro clarificar le conducta therapeutic, viste le consilios contradictori trovate in le manuales currentemente in uso. Il es un observation commun que iste lesion pote esser le fonte de symptomas perdurative.

Le scrutinio del fracturas revela le existentia de quatro typos de illo. Duo occurre al junction inter diaphyse e base e se distingue per le presentia o absentia de comminution. Le altere duo occurre al base del processo styloide e se distingue per le presentia o absentia de un affection del articulation metatarso-cuboide.

Le analyse del conformation del varie fracturas supporta le these que iste lesion es causate per fortias tanto directe como etiam indirecte que affice le margine lateral del pede durante que le calce es sublevate. Le experientia del sala de operation e studios anatomic non incrimina le peroneo breve sed plus tosto le forte attachamentos del articulation metatarso-cuboide

Iste classification provide principos rational pro le election de immobilisation per gypso, de fixation interne, o de plus simple mesuras de tractamento.

20

Treatment of Ischemic Gangrene and Infection in the Foot

HERBERT E. PEDERSEN, M.D.*

There has been considerable discussion in recent years concerning the advantages and the disadvantages of low amputation for gangrene. While it has been demonstrated that low amputation is advantageous, safe and usually successful, there has been little general enthusiasm for conservatism. In many medical communities, for the patient with gangrene limited to toes the recommendations for treatment run from allowing spontaneous separation of the involved toe to performing a mid-thigh amputation. The purpose here is to discuss the methods of managing conservatively ischemic necrosis in the foot and to reconcile such divergent attitudes. The convictions expressed are based on a 10-year experience with an active amputation service, but the principles involved were expressed originally by others, such as Samuels,[3] McKittrick,[2] Silbert,[4,5] and Furste and Herrman.[1]

With increasing longevity we are concerned more and more with the care of the elderly patient and the means of ensuring his independence. On any amputation service it is soon obvious that the higher a lower extremity amputation is performed, the more difficulty the elderly patient has with a prosthesis and ambulation. In spite of improvements in prostheses and in methods of training, few elderly above-the-knee amputees walk well. It has also been demonstrated that the elderly patient lives long enough after amputation for us to be concerned with rehabilitation. Silbert showed that among diabetics, about half of the amputees lived longer than 5 years and that about half of those had the second leg amputated in less than 5 years.

Conservative amputation became possible when mortality rates declined to the point where they no longer precluded a possible second major amputation. The operative mortality rate for amputations below the ankle, among properly selected patients, should be negligible, and reamputation at a higher level should not increase it significantly.

With the recent concentrated attack on peripheral vascular problems, important observations have been made. It has long been known that in Buerger's disease an abundant collateral circulation develops. It has only recently been recognized that in arteriosclerosis, with or without diabetes, a gradual occlusion of major vessels may be associated with the development of an adequate collateral circulation. Thus, an extremity without a palpable pulse may have a circulation adequate for nutrition and function.

Among patients with arteriosclerosis, gangrene is precipitated in one of two ways: either there is a sudden occlusion of a major vessel or in the progressively ischemic limb some peripheral insult leads to local thromboses or a localized increased demand for blood that is not available. Almost invari-

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ably, patients in the first category require a major amputation, and those in the second are candidates for conservative management.

If gangrene begins distally from some local insult and infection is controlled, following demarcation amputation may be performed at any proximal level consistent with good function, provided that the skin at that level is warm and shows evidence of good nutrition. It does not seem necessary to perform any of the many tests designed to test the amount of peripheral blood supply. The patient must be observed long enough to be certain that gangrene is not progressive, and, as much as possible, factors that contribute to progressive gangrene must be eliminated. Chief among these is infection.

It must be assumed that in all patients with gangrene some degree of infection exists. In "dry" gangrene a break in the skin soon develops at the junction between viable and necrotic tissue, and in that area pus usually can be found. It was to prevent superimposed infection that Samuels urged that these extremities be covered with sterile dressings during conservative treatment. Surface infection can be controlled with tepid, soapy foot baths, sterile dressings, and antibiotics when indicated. In the foot with minor areas of gangrene, undrained deep infection is the most common cause of progressive gangrene and results in many needless major amputations. Abscesses must be drained early by incision and drainage, open amputation of toes, open wedge resection of an involved ray of the foot or supramalleolar guillotine amputation. Subcutaneous abscesses on the dorsum of the foot are handled by incision and drainage. Unfortunately, it is more frequently true that infection spreads along the flexor tendons to the deep structures of the foot That infection must be drained by creating a cloven foot, usually resecting one involved toe and metatarsal At the time of the wedge resection, no attempt is made to excise all necrotic tissue, and the wound is packed open loosely. During treatment at rest, with soaks and antibiotics, infection is controlled, and necrotic tissue separates gradually. For several weeks after such a resection, the wound is foul smelling and grossly necrotic. One must not feel rushed at that time into performing a higher amputation. If at the time of the initial examination it was recognized that the patient was a suitable candidate for low amputation, then persistent conservative care will almost always lead to good secondary healing. With progressive granulation the cleft closes gradually, the result being a foot that functions excellently. Whenever infection is controlled, amputation may be performed at a higher level if function demands.

For the patient whose gangrene is limited to toes, there are several choices of treatment. A mummified toe without gross infection can be allowed to separate spontaneously. The separation can be assisted by softening ointments and daily soaks. Later, the separation is assisted by cutting, with scissors or knife, just distal to the line of demarcation, care being taken to ensure that no incision is made through viable tissue. Then secondary healing usually results in good function.

If demarcation occurs distal to the base of the toe, without gross infection, formal closed amputation of the toe can be performed. For several reasons, when more than one toe is involved or the entire first toe is involved, our own preference is for the transmetatarsal amputation. The most vulnerable portion of the lower extremity is the toe. It is well known that frequently one episode of gangrene involving toes is soon followed by another. Too often, infection superimposed on ischemic necrosis leads to progressive gangrene that is not controlled until a major amputation is necessary. On the other hand, it is rare for gangrene to begin distally in a well-healed transmetatarsal stump. Finally, following the loss of the first toe, there is little function to be gained from the lateral toes. The patient with a well-healed transmetatarsal amputation

walks well without a prosthesis. For the above reasons, even though gangrene is limited to one toe, and that toe might be treated by local amputation, a transmetatarsal amputation frequently is indicated.

Conservative amputation has failed to gain popularity for two obvious reasons:

The first of these concerns the patient with borderline indications, where success or failure cannot be predicted accurately. In evaluating such patients it is necessary, preoperatively, to consider carefully the many factors that would favor early healing and those that suggest failure. Obviously, the better the peripheral blood flow, the better the chance of primary wound healing. Quite frequently the diabetic has gangrenous toes with an easily palpable dorsalis pedis and posterior tibial pulse, suggesting an almost normal circulation in the same foot. If the line of demarcation is sharp and the skin at the proposed level of amputation is warm, dry and well nourished, successful low amputation should be the rule, with or without a palpable pulse. If the skin above the level of demarcation is cool, thin and shiny, with absent pulsation, then local circulation is poor, and successful low amputation is improbable. A most unfavorable sign is the presence of severe rest pain in the absence of gross infection. Frequently, this type of cool, painful foot is the result of a higher thrombosis. Gangrene may be quite limited, and the remaining peripheral blood flow is just sufficient for life of tissue at rest. Many of the unsuccessful transmetatarsal amputations have resulted from treating such patients. In those circumstances the surgeon may be tempted, against his better judgment, to perform a transmetatarsal amputation after the performance of a lumbar sympathectomy. In our experience, lumbar sympathectomy neither prevents the advancement of gangrene nor lowers the possible level of amputation. More often it is better to treat the patient with a cool, painful foot by below-the-knee amputation.

The second major deterrent to increased interest in conservatism is the difficulty encountered in getting primary healing. There is some type of wound complication following about half of the operations. The wound complications are divided almost evenly between infection and ischemic necrosis of the wound edges.

Both types of wound complication can be managed successfully by conservative methods similar to those used in preparing the foot for the initial surgery. Ischemic necrosis of wound margins is treated by allowing spontaneous separation of the necrotic areas while using daily soaks and continued sterile dressings. The occasional patient has an extensive progression of gangrene with loss of the entire flap, for which only reamputation at a higher level is adequate treatment.

Postoperative wound infection must be recognized early. If there is unusual pain or fever, the wound must be inspected early. Sutures should be removed early for stitch abscesses. If there is any suggestion of deep wound infection, all sutures should be removed, the flaps opened widely, and the program of rest, soaks, dressings and antibiotics resumed. Deep, undrained infection is a common cause of postoperative extension of gangrene for which reamputation becomes necessary. Furste and Herrman suggested delayed wound closure to prevent such complications. Our own preference is for primary wound closure and for careful evaluation of the early postoperative course.

For either type of postoperative wound complication, no matter how extensive, secondary healing usually requires 3 or more months of careful management. As was true in the management of open toe amputations, incision and drainage, and the wedge resection of the foot, there is no short cut to early healing. The temptation to perform daily débridement is great, but it can only be followed by progressive slough. Also, there is little likelihood that skin-grafting of granulating areas will be successful. If the surgeon's preoperative evaluation of the circulatory status convinced him that low ampu-

tation was indicated, then his confidence in the successful management of the wound complication is soon transmitted to the patient. When the lesion is stabilized and granulation tissue appears, the patient and his family are instructed in the proper local daily care, and the patient is discharged to outpatient care. The patient then should be able to walk a little.

Since the treatment of early gangrene and of postoperative wound complications can be carried out on an outpatient basis, prolonged periods of hospitalization are not necessary. In most cases the cost of hospital care to the patient should not be a deterrent to conservative amputation. On the other hand, it should be recognized that following a high amputation there is the additional cost of supplying and maintaining a prosthesis and of teaching the wearer to walk properly. For those elderly patients who cannot ever walk with a prosthesis, the economic burden of constant nursing care and the loss of productivity to society cannot be estimated. These financial considerations are mentioned only because it has been said that conservative care is in many cases impractical and too costly.

SUMMARY

1. In the presence of gangrene that begins distally from some local tissue insult, every effort should be made to preserve extremity length.

2. Local amputation is indicated when gangrene is sharply demarcated and infection is controlled, provided that the skin at the proposed amputation site is warm and dry and shows evidence of good nutrition.

3. In the presence of peripheral vascular disease, local amputation for gangrene cannot be successful unless local infection is well controlled.

4. There is little evidence to suggest that lumbar sympathectomy prevents the progress of gangrene or that it permits a lower amputation than would otherwise be possible.

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Tractamento de Gangrena Ischemic e de Infection del Pede

Summario in Interlingua

In le presentia de gangrena que comencia in un sito distal ab un insulta al tissu local, omne effortio deberea esser facite pro preservar longor del extremitate.

Amputation local es indicate quando le gangrena es nettemente demarcate e quando le infection es subjugate, providite que le pelle in le area del amputation es calide, sic, e evidentemente ben nutrite.

In le presentia de morbo periphero-vascular, amputation local non pote resultar in successo, excepte si le infection es ben subjugate.

Il existe pauc indicationes que suggere que sympathectomia lumbar preveni le progresso de gangrena o que illo permitte un plus basse amputation que esserea alteremente possibile.

21

Metatarsus Varus and Hip Dysplasia

Julian E. Jacobs, M.D.*

The purpose of this chapter is to make a plea for the early diagnosis of congenital hip dysplasia, often associated with metatarsus varus. If such diagnosis can prevent 20 per cent[12] of all painful osteoarthritic hips in the geriatric groups 30 or 50 years hence, a great service is being rendered these individuals both now and in the future.

Some of the signs to be described have appeared in recent orthopaedic literature but have not as yet made their appearance in the latest orthopaedic and pediatric textbooks, so that they are not readily available. Inasmuch as the prognosis for a normal hip is excellent if treatment is started early (first week or 2 to 18 months), both the hip and the foot condition can be treated simultaneously.

The term *congenital hip dysplasia* was introduced by Hilgenreiner.[7] It is a general term, denoting, as Gill[5] described, delayed or defective development of the hip joint and its associated structures. In this regard, it may be considered a precursor of the clinical entities of subluxation and dislocation of the hip.

The latest concept of congenital dysplasia of the hip is that it is a lack of development of the acetabular rim, a primary condition. This defect is inherited and has been shown to run in families. Hart[6] states that congenital dysplasia of the hip can and should be recognized in the first 6 months of life; that is, before weight-bearing. Therefore, if an occasional suspected case is treated mistakenly by braces or plaster for a few months for congenital subluxation or dislocation, no great harm has been done. However, if even a few of the true dysplasias are neglected or are not recognized, permanent fixed deformities will result, and a greater or a lesser disability will occur in later life.

Colonna[4] mentions the association of hip dysplasia and metatarsus adductus of one or both feet and occasional calcaneovalgus, cavus or calcaneus deformity in his studies. He states:

> Most of these children, when they began weight-bearing, were fitted with shoe wedge correction, for they nearly all had pronation of their feet.

He gave no percentage of incidence of the foot abnormalities as related to the hip condition that he found.

Caffey and his co-workers,[2] writing on the congenital dysplasias, feel that many cases have been diagnosed erroneously as subluxation or dislocation and that, without any treatment whatsoever, time has shown that many of these return to normal hips. To date, these observers have examined about 5,000 babies and have given specific attention to the question of hip dysplasia. They point out that in this number of infants examined routinely, less than half a dozen dysplastic hips were found, although many of these babies possessed clinical features recognized ordinarily as definite stigmata of dysplasia. They do not differentiate very clearly between dislocations and subluxations but express surprise at the small number of truly abnormal hips. The small number of dysplastic hips found by these authors is not

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surprising, for the condition is not a common one in the population at large. No mention was made of associated foot conditions.

Coleman[3] reviewed 3,500 infants and found congenital hip dysplasia in 32. This represents less than 1 per cent, but he gave no associated findings of either metatarsus varus or calcaneovalgus feet. It is our feeling that if all patients with metatarsus varus deformities were to have the hips x-rayed, a much higher incidence of hip dysplasia would be found.

Kite,[10] in his excellent paper on congenital metatarsus varus—a report of 300 cases —felt that congenital metatarsus varus was on the increase, and this is our feeling. He personally had not seen any increase in the incidence of congenital club feet but had encountered a marked increase in metatarsus varus. He also indicated that mild cases of metatarsus varus might be overlooked in the *first few weeks of infancy, but that, as the* persistent action of the anterior tibial muscle continued, increasing deformity of the forefoot could and would be noticed. It is at this time—6 weeks to 6 months—that the general practitioner or the pediatrician would make this observation. If, therefore, metatarsus varus is on the increase, will we see a corresponding increase in hip dysplasia?

So far, we know of no genes relating to metatarsus varus, but dysplasia, which frequently associated with it, can be inherited and has been shown to run in families.[6]

MATERIALS AND METHODS

We reviewed 300 consecutive cases of metatarsus varus as the presenting complaint by the parents at our office and found 30 cases of hip dysplasia (10%). We then started to look through the literature to find any similar relationships recorded and have already mentioned these briefly. No comparable series and percentage relationship have been recorded. If this presenting complaint, then, of a metatarsus varus is projected into more detailed examination of the hips, what will this bring forth in the higher incidence of hip dysplasia in the future and the possible prevention of osteoarthritic hips 30 to 50 years from now?

Physical Findings. The affected hip cannot be moved as freely as the opposite one. Frequently it may be more difficult to place a diaper around one hip than the other. Abduction of the affected hip is limited. If the baby is placed on a hard table with limbs flexed at the knees and the hips, and the legs are abducted gradually at the hips, the lateral surface of the subluxated hip cannot be brought flat against the table. This adduction contracture is now being stressed in orthopaedic circles as the most consistent physical finding, and it occurred in 80 per cent, or 24, of our cases.

The Ortolani sign[13] can be demonstrated early. If the pelvis is held snugly against the table, the knee grasped and the hip abducted and adducted gradually, a click may be heard. This is called the jerk of entry and of exit and represents the head's sliding in and out of the shallow acetabulum over the posterior rim of the socket. This sign was positive in 33 per cent of our cases and in Coleman's.[3]

Von Rosen[16] reviewed approximately 12,000 babies at Malmö, Sweden. In only 17 hips was the Ortolani click demonstrated Of course, he was describing more of the true luxations and subluxations than a simple dysplasia of the hip. It is for this reason that I hope the associated findings to be outlined will allow the practitioner to make the diagnosis more often and the cure more certain

Increase and deepening of the asymmetric gluteal folds on the affected side suggest an incomplete dislocation (Fig. 1), and this occurred in 100 per cent of our cases.

The Allis sign is detected by flexing both the infant's hips at right angles while the child lies on a hard surface. The knee on the affected side will be at a slightly lower level than on the other side. This occurred in 20 per cent of our cases. This test is rarely positive in the newborn; it is more

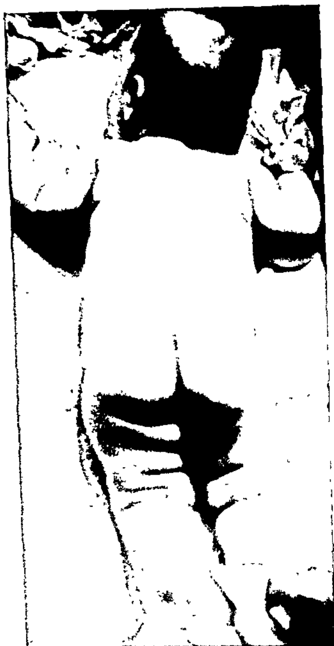


FIG. 1. Increase and deepening of asymmetric gluteal fold—metatarsus varus and dysplastic hip on left.



FIG. 2. Delayed capital femoral epiphysis.

obvious in the 3- to 10-month-old infants.

The anatomic factors that may permit these situations are the excessive laxity of the capsule and the ligaments about the hip and unusual shallowness of the acetabulum. Howorth[9] suggests that capsular laxity is the principal fault that initiates the chain of events leading to ultimate dislocation of the hip. Ortolani,[13] on the other hand, found in studying three fetal dislocations at autopsy that deficiency of the posterior acetabular rim was the major fault. It is concluded from these studies that both conditions play a role in the pathogenesis of hip dysplasia in the newborn infant.

Roentgen Findings. The development of the capital femoral epiphysis is often delayed on the affected side (Fig. 2). In half the children this epiphysis is evident shortly after birth and is always seen within the first 3 months.

Hilgenreiner's measurements were done in our cases but were not diagnostic enough to present as a major radiologic examination. They are of slight value in unilateral cases.

The "Y" line represents the horizontal line (Hilgenreiner)[8] drawn through the clear areas in the depth of the acetabula that represents the triradiate or "Y" cartilage. The "H" and the "D" lines are shown in Figure 3 and represent the distance (H) between the "Y"-line and the highest point on the femoral neck (or head if present) and (D)

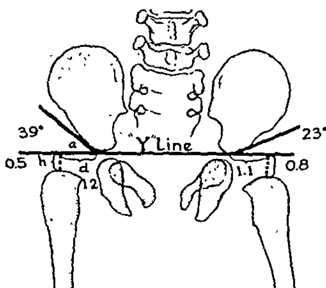


FIG. 3. "Y" line is horizontal line drawn through comparable points on triradiate cartilage; angle "a" is acetabular index; "h" is distance between "Y" line and highest point on femoral neck; "d" is distance between triradiate cartilage and intersection of "h" and "Y" line.

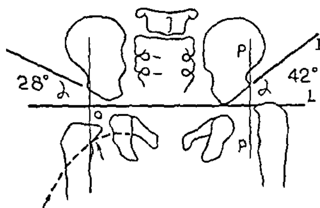


FIG. 4. Perkins' line, a vertical line through outer edge of acetabular rim makes quadrant with "Y" (or "L") line; normal hip on right with capital epiphysis in mesial quadrant; dysplastic hip on left displaced laterally. Arrow points to Shenton's line, the gentle continuous curve of the obturator foramen and femoral neck.



FIG. 5. Dysplastic hip and metatarsus varus, left, in an infant. (*Top*) At 7 weeks shows acetabular index 40° (right 30°). (*Bottom*) At 8 months shows an acetabular index, left, of 25°, delayed epiphysis above Shenton's line. This returned mesially to Perkins' line after treatment.

the distance between the triradiate cartilage and intersection of "H" and "Y."

Another vertical line (Perkins') (Fig. 4) is drawn through the outer edge of the acetabular rim, and the quadrant formed with the "Y" line shows the normal capital epiphysis (or femoral beak in newborn) to be in the lower medial quadrant and medial to Perkins' line.

In hip dysplasia the shallow cartilaginous acetabulum pushes the spine-shaped rudimentary neck of the femur or the femoral head lateral or upward to Perkins' line. This was positive in 50 per cent of our cases (Fig. 5). We agree with Coleman[3] that this radiologic finding is of more value than the acetabular index This applies particularly to bilateral cases (10% of our cases) (Fig. 6).

The acetabular index (Fig. 7) is in-

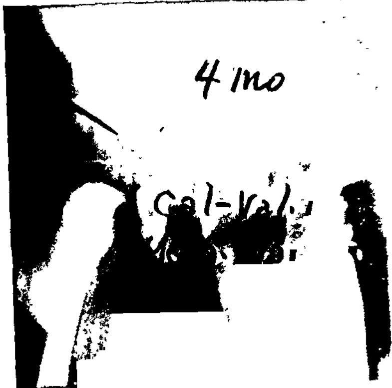


Fig. 6. Both hips lateral to Perkins' line.



Fig. 7. Acetabular index 31° on left and 22° on right. (Metatarsus varus on left)

creased The index is the degree of the angle formed by a line through the triradiate cartilage of both hip joints and another line along the ossified outline of the superior portion of the acetabulum. Usually this angle is about 20° in a child of 2 years. A 30° angle in the first year of life is indicative of an abnormal insecure acetabulum,[11] but an index of 40° or more is a better sign radiologically of a true dysplasia.[3]

In upward displacement of the femoral head, the lower neck border is found to be above Shenton's line (Fig. 8), which in normal hips is an even arc formed by the

medial border of the neck of the femur and the superior border of the obturator foramen. This is difficult to evaluate in the newborn.

DISCUSSION

Discussing the so-called accepted physical findings for either congenital hip dysplasia or congenital dislocation of the hip, the impression was gained that in the newborn infant the usual criteria for the diagnosis of these conditions were inadequate and unreliable. Most of the conventional signs were later developments, occurring secondary to the progression of the hip dysplasia. The absence in some of our cases of limited abduction (often stressed as the No. 1 clinical sign on physical examination) can be explained on the basis of a lax capsule or socket of inadequate depth. In fact, the adduction contracture becomes worse in the ensuing months if the patient has not been treated. The skin folds of a newborn infant are difficult to interpret, and asymmetric skin folds are only suggestive. Howorth[9] suggests that the infantile hip flexion contracture is a phase in the normal development of the hip joint as it passes from the flexed to the extended position. Certainly such variable factors influence the formation of the skin creases, making them diagnostically not reliable. Sherman Coleman[3] feels that skin creases are virtually meaningless. We, however, feel that they are another sign to be looked for, and, if positive (100% of our cases), add to the diagnosis. Unilateral shortening of one extremity (Allis's sign) was difficult to determine in the newborn, but it did show up progressively more in the ensuing months up to a year (20% of our cases). We found this sign to be positive in our hip cases over 4 months of age. We agree with Coleman that in the newborn infant and in the first several months of infancy, the jerk of exit of Ortolani's maneuver is the principal reliable physical finding that suggests hip dysplasia (33% of our cases). This, however, requires a gentle, well-controlled attempt to displace the hip laterally or posteriorly. No undue force is necessary.

In discussing the roentgen findings, the acetabular index is stated as the angle that the slope of the acetabular roof makes with a horizontal line drawn through comparable points in the triradiate cartilage (Fig 7).

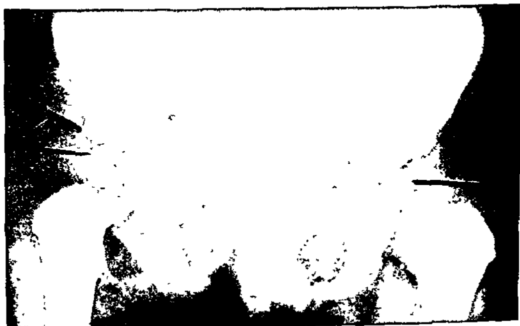


FIG 8 Femoral neck above Shenton's line, delayed epiphysis and acetabular index of 40° (Metatarsus varus on same side.) 13 months.

Hilgenreiner[9] drew attention to the possible diagnostic significance of this angle in 1925. Kleinburg and Lieberman,[11] on the basis of x-ray examinations of 23 newborn infants, concluded that an acetabular index above 30° at birth suggested a potential dislocation of the hip. Coleman, however, in studying 300 newborn hips, could not substantiate these figures; he showed that a 30° acetabular angle was the average of newborn infants. Brewer[1] agrees with these findings. Our variations went from 28° to 49°. In Coleman's dysplasia of the hips in his 27 roentgenograms, the acetabular index averaged 36.5°, showing an index of 6° higher than the values encountered in normal hips of the same age. He showed, therefore, that the acetabular index by itself could not be relied upon without the other clinical and radiologic findings. We certainly agree that Shenton's line is very difficult to appraise accurately in roentgenograms of newborn infants, because the ossification centers are quite widely spaced and slight degrees of change in pelvic tilt have a marked influence on this line. Hilgenreiner's measurements consist of the "H" line and the "D" line, as illustrated in Figure 3. This particular measurement is of value only if there is a unilateral involvement. Radiologically, the most common change seen in abnormal hips in infancy up to 6 months is the lateral disposition of the beak of the femoral neck in relation to Perkins' line. In normal hips the beak of the femoral neck falls medial to Perkins' line with remarkable constancy, and in our cases 15 showed lateral displacement to this line. This radiographic finding can be used particularly in cases of bilateral dysplasia (Fig. 6). Coleman found it to be positive in 58.1 per cent of his cases of dysplasia of the hip. We found it to be positive in 50 per cent of our cases. In unilateral cases the delayed appearance of the epiphyseal femoral head was of some help.

X-ray examination, therefore, can provide helpful information in many of these cases, but care must be exercised in interpretation. Coleman felt that an acetabular index of 40° or more should be recorded before it became significant. Consequently, the diagnosis of hip dysplasia requires a correlation of x-ray and clinical findings. Certainly a normal roentgenographic interpretation of an infant's pelvis does not necessarily rule out a congenital hip dysplasia. In summarizing the criteria for a diagnosis, we have used the following:

	Cases
1. Asymmetric gluteal folds	100%
2. Limited abduction (flexed thighs)	80%
3. Lateral displacement—Perkins' line	50%
4. Ortolani's sign—jerk of exit	33%
5. Acetabular index—30°+	25%
6. Allis's sign—knee at lower level	20%
7. Delayed or smaller epiphysis (upper femoral)	15%
8. Associated foot deformities (metatarsus varus)	10%

INCIDENCE OF DYSPLASIA OF THE HIP

Coleman's incidence of 1 in every 110 births is on record. Our incidence of 30 hips associated with 300 consecutive cases of metatarsus varus is another index. One boy and 29 girls were recorded. Three cases were bilateral. No colored patients were noted. Coleman's incidence was a female predominance of 5 to 1. This corresponds with the congenital hip dislocation incidence. Putti gives an incidence of 1 newborn infant in 10 having dysplasia of the hip,[14] and Slavick[15] states that 20 per cent of newborn infants in Czechoslovakia exhibit some form of congenital hip dysplasia. Coleman indicated that unstable hips occurred twice as often in breech as in cephalic deliveries.

It is apparent from all this that a significant number of abnormalities pass undiagnosed at birth at every hospital. However, failure to make the diagnosis after several months of observation in one's office is negligence. The tragedy of overlooking a complete congenital dislocation of the hip until the age of walking is almost matched by the tragedy of undiagnosed subluxations of the hip. These latter cases may not be detected until the age of 30 to 50

plete the diagnosis. It is common knowledge that a significant number of dysplasias become stable spontaneously with no treatment at all. However, no one can determine beforehand which of these will heal spontaneously and which will persist as subluxations. Some will even go on to frank dislocations.

We have had 2 cases of unilateral progressive dysplasia (with associated metatarsus varus)—one whose treatment was discontinued too early and another who was deliberately observed for 4 months without treatment. The first of these was diagnosed at 4 months of age, treated 2 months in a bar, then observed for 4 months with progressive lateral displacement of the femoral head, with increase of the acetabular index from 28° to 42°. After 4 more months of treatment in a bar 24 hours a day, the hip returned to more normal findings, and after 4 more months (age 18 months) of nap and night bar, the hip required no more treatment. The second child was treated for metatarsus varus elsewhere at age 4 months and was seen by us at the age of 8 months. The first roentgenogram of the hips showed homolateral dysplasia. The child was observed at 2-month intervals with no treatment of the hip. The index increased progressively from 30° to 40° in 4 months, when the patient started walking with a limp. Treatment with a bar was instituted, 24 hours a day, for the first four months, then for 4 months for nap and night, with final return to normal at age 20 months. Both these cases have been followed for 3 years.

Inasmuch as the treatment is simple, it is obligatory to treat all patients in whom there is a suggestion of hip dysplasia. The majority of these patients can be treated over a few months and restored completely to normal.

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Metatarso Var e Dysplasia Coxal

Summario in Interlingua

Esseva revistate 300 casos consecutive de metatarso var in infantes vidite in un clinica orthopedic (in le practica private). Esseva notate un incidentia de dysplasia coxal amontante a 10 pro cento. Le altere criterios pro le diagnose de dysplasia coxal es mentionate: Retardate e sub-dimensionate epiphyse supero-femoral, signo de Allis, *indice acetabular, signo de Ortolani, displa*ciamento lateral del linea de Perkins, limitation in le test de abduction, e asymmetria del plicas glutee.

Viste que le tractamento es simple e que su application pote prevenir 20 pro cento de omne casos de dolorose coxa osteoarthritic in le futuro, il pare que nos ha le obligation de signalar iste diagnose al medicos qui es le primes a vider le infantes con iste condition.

Le statistica indica que il occurre un augmento in le incidentia de metatarso var e un reduction del incidentia de talipede in iste pais. *Nos urge le examine radiographic* del coxa de omne patientes con deformitates del pede a fin que iste infantes gaude del opportunitate de un precoce e successose tractamento.

22

Congenital Vertical Talus*

Tom Outland, M.D., and Henry H. Sherk, M.D.†

The entity of congenital vertical talus, although rare, has begun to receive more attention recently in the orthopaedic literature. Various names such as "rocker-foot due to congenital subluxation of the talus"[1] and "congenital convex pes planus"[6] have been applied to it. They are, as is the name used here, descriptive and in themselves provide a good understanding of the abnormality. The important feature is the subluxation of the talus, resulting in the almost vertical position of this structure in the foot. Its long axis forms an angle of almost 180° with the long axis of the tibia. The os calcis, from which the talus is displaced medially and vertically, is itself usually in slight equinus. The forefoot, however, "breaks" at the mid-tarsal joint with subluxation of the navicular from the head onto the neck of the vertical talus. The tendons on the dorsum of the foot usually are contracted, and the capsule of the ankle joint has been noted to be interposed between the talus and the navicular. In addition, the tendo achillis usually is tight, consistent with the degree of equinus of the calcaneus. In older cases the posterior capsule of the ankle joint is contracted, and the spring ligament is attenuated.[1,4,6,10]

Clinically, on the medial aspect of the foot the longitudinal arch is reversed. The sole of the foot is convex instead of concave, and there is a prominence in the sole corresponding to the mid-tarsal articulation and the head of the talus. The forefoot is abducted, and on the dorsum of the foot there is a sulcus anterior to the lateral malleolus due to the displacement of the talus away from its normal alignment in this location. The roentgenologic appearance of the foot is highly characteristic. The talus in the vertical position, the os calcis in slight equinus and the dorsal dislocation of the navicular onto the neck of the talus com-



Fig. 1. Lateral view demonstrating the convex sole with a prominence over the head of the talus.

* The authors are indebted to Mr Francis Gilmore, of Elizabethtown, Pa , for the illustrations

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Fig. 2. Note the vertical talus, displaced navicular and heel in the equinus position.



prise the abnormality and are readily discernible on the roentgenograms (Figs. 1 & 2).

TREATMENT

In older, neglected cases, the results of treatment of congenital vertical talus frequently are unsatisfactory. Therefore, the importance of early treatment is stressed by all writers on the subject. Conservative management, consisting of application of corrective casts in infancy, has been attempted. The foot is held in the cast in complete equinus, correcting the dislocation at the talonavicular and the calcaneocuboid joints. However, there is a marked tendency for the dislocation to recur when the foot is brought up out of equinus. Improvement of appearance and function may be noted temporarily, but lasting correction seldom is obtained. The same is said to be true of other conservative methods, as the Denis-Browne hobble splint (reversed), the iron and T strap, corrective shoes and night splints.[8]

The operative treatment of congenital vertical talus, then, seems to be the approach that offers more promise with regard to good long-term results. However, surgery in this condition is not a panacea, and writers on the subject suggest a wide variety of technics and methods for the management of this problem. These are summarized in the following table. A valid end-result summary

Technics for Management of Congenital Vertical Talus

I. Resection of all or part of the talus:
   1. Complete astragalectomy—Lamy, 1939
   2. Excision of head and neck of talus: Lange, 1912; Nave, 1923; Hark, 1950 (grafted resected head back to anterior surface of vertical talus)

II Corrective osteotomy:
   1. Hughes, 1957 (osteotomy of neck of talus, open wedge on plantar aspect maintained by bone graft)
   2. Lloyd-Roberts, 1958 (wedge tarsectomy)

III. Open reduction:
   1. Osmond-Clarke, 1956 (maintained reduction with peroneus brevis tendon transposed to neck of talus)
   2. Hark, 1950 (heel-cord lengthening, release of tight structures on dorsum of foot, reduction maintained in plaster with or without Kirschner wire through the navicular into the head of the talus)
   3. Hughes, 1957 (scarification of talonavicular joint with or without maintaining reduction with Kirschner wires)
   4. Rocher, 1934 (release dorsal and lateral soft-tissue elements, section Achilles tendon, maintain correction in plaster)
   5. Heyman, 1959 (open reduction maintained with Kirschner wires)

IV. Miscellaneous:
   1. Camera, 1926 (curette talus, resect cuneiform portion of astragalus)
   2. Lloyd-Roberts, 1958 (reduction in plaster and tenotomy of tibialis anterior)

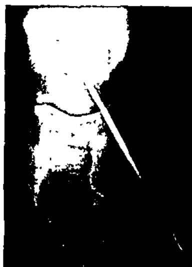



FIG. 3. Roentgenograms of a cadaver foot with the Kirschner wire in place.

for each technic cannot be included because the number of cases in any given series is small, and the follow-up sometimes is not adequate.

CASE REPORT

A 3-year-old boy was admitted to the Elizabethtown State Hospital for Crippled Children with the diagnosis of a congenital vertical talus He had been treated conservatively with braces, shoes and physical therapy on an outpatient basis for 2 years prior to admission. The conservative approach, however, had been unsuccessful, and it was apparent that operative correction would be necessary. Three procedures were carried out to achieve this

The first was the open reduction of the vertical talus through a lateral Ollier incision However, the talus could not be maintained in its normal position, and it was necessary to make another incision on the dorsum of the foot through which the tendons of the common toe extensors and the extensor hallucis were released, and the anterior tibial tendon was lengthened by Z-plasty. The talonavicular joint then was approximated, and a smooth Kirschner wire was driven through the navicular to the medial side of the foot and retrograded into the head of the talus (Fig. 3). By this means the subluxation of the navicular was reduced and main-



FIG. 4. After removal of the Kirschner wire and prior to the extra-articular subtalar arthrodesis.



FIG. 5. Eighteen months after extra-articular subtalar arthrodesis with maintenance of corrected position of the talus.

tained in its normal position (Fig. 4). The foot was immobilized in plaster for 6 weeks, and the pin then was removed. After 6 more weeks in plaster the maintenance of the normal position of the talus was ensured further by an extra-articular subtalar arthrodesis[3] (Fig. 5). The equinus of the os calcis was corrected by a heel-cord lengthening 3 months after this second procedure The patient's foot structurally and functionally was considerably improved at the *time of discharge, although the heel was in* slight varus, indicating a moderate amount of overcorrection. It will probably be necessary to do a triple arthrodesis at a later date, but this procedure will be greatly facilitated by the more normal alignment of the foot achieved at this time. Furthermore, the chances of a good final result will be correspondingly improved.

SUMMARY

1. The pathologic anatomy, the clinical findings and the radiologic features of congenital vertical talus are presented.

2. The various approaches to the management of this condition are summarized.

3. A new operative approach is presented. This consists of open reduction of the congenitally subluxated talus, release of the deforming soft tissues and maintenance of the reduction with a Kirschner wire through the navicular into the head of the talus At a later date, after the wire is removed, the reduction is maintained with an extra-articular subtalar fusion. The equinus is corrected with a heel-cord lengthening. A subsequent triple arthrodesis is necessary when the foot reaches skeletal maturity.



FIG. 6. Eleven months following elevation of the vertical talus, extra-articular subtalar fusion and heel-cord lengthening.

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Section II

GENERAL ORTHOPAEDICS

23

Leg-Length Equalization by Femoral Shortening

M. JOHN ROWE, JR., M.D.,
AND
G. D. BOCK, M.D.*

Unequal leg length is a serious functional and cosmetic problem. Complications can develop; for example, muscular and fascial contractures leading to pelvic obliquity and scoliosis. Poor gait habits may become grotesque, causing the individual to develop defective personality traits that add a psychological to a physical handicap.

A short leg is seen most often in poliomyelitis, where the child has favored the weak extremity so that its weight-bearing function has been much less than that of the longer leg. This same effect is seen in the club foot congenital deformity of one leg where the child will hop or skip on the better extremity. Pyogenic septic arthritis or tuberculosis may arrest growth of an epiphysis. Trauma may either shorten with malposition or lengthen by stimulation of growth. Osteomyelitis can either arrest or stimulate.

The condition should be prevented when possible. The paralytic extremity should be watched carefully to prevent deformity and to maintain equal weight-bearing. Pounding or skipping exercises are performed to give functional stimulation.

When the inequality has occurred, correction is somewhat controversial. In most cases, surgical lengthening of the short extremity has been sufficiently ineffective and hazardous to be discarded as a method for consideration according to Sofield.[7]

Theoretically, stimulation of epiphysial growth, as suggested by Pease[6] and used in a few cases by us by juxta-epiphysial multiple drilling, would seem to be nearly ideal, but practically it has produced only small estimated increases in length.

At present, the consensus under the leadership of Green[3] and Blount[1] favors epiphysial arrest in the longer extremity during the growth period. By calculation from standard tables, operation is done when there appears to be a possibility of eventual equalization of length by further growth of the already faulty and, consequently, unpredictable short leg. This procedure requires extremely close observation over a long time with possible need of repeated operations in patients who are prone to disappear from supervision for extended periods. With the hazard of unequal epiphysial arrest, a new deformity may occur and require treatment in the previously good leg. An example is unequal therapeutic epiphysial arrest with production of genu varum in the good leg. (Fig. 1)

The procedure of definitive femoral shortening at or near the end of the growth period with supervision over a relatively short length of time appears to be safer and more efficient. White[9] described an early method with over-

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lapping of femoral fragments and both internal and external fixation that was quite effective. With the appearance of the intramedullary nail, the procedure is even less disabling because of the early ambulation possible. This procedure has been criticized by Thompson[8] and recommended by Jones.[4]

The program that we are using consists of

(1) sufficient shoe lift to level the pelvis. Up to 2-inch discrepancies are corrected with standard heel and sole lifts using a "fast rocker" tapering to the toe when the knee function is good and a nontapering "slow rocker" with a poor knee as advised by Lowman.[5] (Figs. 2 and 3) For shortening over 2 inches, a stirrup type of brace is used, like a walking iron on a cast. Stamping or pounding exercises are advised daily for the short leg to attempt to maintain proportional growth and prevent further lag.

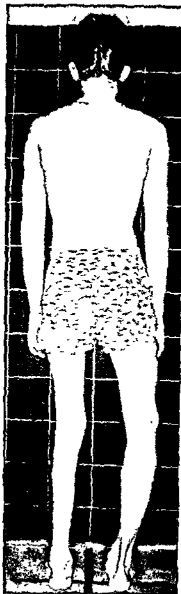


FIG 1. Therapeutic epiphysial arrest with irregular growth and genu varum of longer extremity

(2) growth checked by clinical measurement, by leveling blocks under the foot, and by leg-length roentgenograms of the type advised by Farill[3] at about 6-month intervals. The roentgenograms are very helpful in showing the total discrepancy on one standard 14 × 17 film. These are made by moving the blocked-off cassette and tube to take three vertical projections of the hips, the knees and the ankles so that the difference in length of the extremities can be measured.

(3) surgical correction at or near the end of the growth period of differences in length of more than 2 cm. for which normal lateral pelvic mobility cannot compensate. With the patient in the lateral position, a posterolateral longitudinal exposure of the mid femur is done, and a measured segment of shaft is removed by transverse sections with the reciprocating saw. A large double-ended, diamond-shaped intramedullary nail is inserted retrograde in the proximal segment through a skin puncture above the trochanter and then distally in the reduced distal femoral segment. Rotation is controlled by the shape of the pin. Soft-tissue shortening with early weight-bearing maintains apposition. No external fixation is necessary, and the pin is removed after union through a small stab wound above the trochanter.

Twelve children are presented (see table on page 223) with an average age at operation of 15½ years. There were 7 females and 5 males. Poliomyelitis was the cause of the shortening in 9, septic arthritis in 1, tuberculosis of the hip in 1, and spastic paraplegia with old fracture in 1. The average hospital stay for the operation was 9 days.

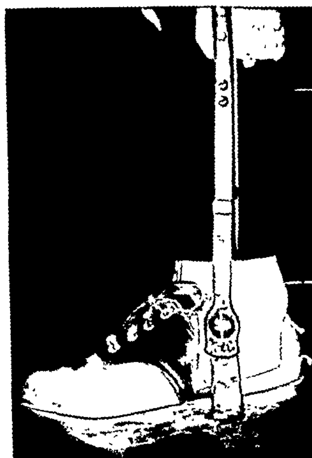


FIG. 2. "Fast rocker" shoe for use with good knee.



FIG. 3. "Slow rocker" shoe for use with poor knee quadriceps.

Our first case, a 19-year-old girl, had 1½-inch shortening on the left following a septic hip. The right femur was shortened with a Blount blade plate in 1947 with a 29-day hospital stay and excellent result. (Fig. 4)

The present technic was started in 1952, and Case 4, a girl of 17, with severe generalized paralysis and shortening of 1½ inches of the left leg, was operated upon in 1953. Her postoperative roentgenogram showed

PARTICULARS OF 12 CHILDREN WHO UNDERWENT SURGERY; AVERAGE AGE AT OPERATION 15½ YEARS

PATIENT/SEX/AGE	ETIOLOGY	EXTREMITY	SHORTENING	SURGERY	HOSP. TIME DAYS	PIN REMOVED	COMPLIC.	RESULT
1. N.W./F/19	Septic hip	L	1½"	2/19/47	29	Blade plate	None	Good
2 B.A./F/17	Polio	R	1½"	3/26/52	8	11/9/52	None	Good
3. S.M./F/15	Polio	R	1⅛"	1/14/53	7	12/1/53	None	Good
4. A.McC./F/17	Polio	L	1"	6/17/53	14	2/15/54	Separation	Good
5. D.W./M/14	Polio	L	1½"	12/14/54	9	3/28/56	None	Good
6. B H./M/15	Polio	R	1½"	6/15/55	12	2/6/57	None	Good
7. B.K./F/14	Tbc. hip	R	3"	6/29/55	8	4/18/56	None	Good
8 J.M./F/14	Polio	R	1½"	6/13/56	5	2/12/58	None	Good
9. T.P./F/14	Paraplegia	R	1"	8/8/56	1	7/24/57	None	Good
10. G.R./M/16	Polio	R	1⅝"	5/16/57	16	3/3/58	None	Good
11. D.B./M/15	Polio	R	2"	6/8/57	11	11/29/57	None	Good
12. R.B./M/17	Polio	R	2"	8/7/57	9	6/18/58	None	Good

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Particulars of 12 Children Who Underwent Surgery; Average Age at Operation 15½ Years

Patient/Sex/Age	Etiology	Extremity	Shortening	Surgery	Hosp. Time Days	Pin Removed	Complic.	Result
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Fig. 4. N.W. After shortening with Blount blade plate.



Fig. 5. A.McC. Postoperative "separation" treated by weight-bearing and healed.

separation of the fragments that was corrected by weight-bearing started on the second day. This proceeded to uneventful, satisfactory healing. (Fig. 5)

Case 6, B. H., a 15-year-old male, was over 6 feet tall with 1½-inch paralytic shortening of the right leg. He underwent operation on June 15, 1955, and was 12 days in the hospital. The pin was removed on February 6, 1957. (Fig. 6)

Case 7, B. K., a 14-year-old female, had a history of tuberculosis with arthrodesis of the right hip, and the left leg was shortened 3 inches, which was not complete correction but was the maximum that we thought the muscular structures could adopt. The girl was in the hospital 8 days and had the pin removed 10 months later. There were no problems, although a redundant muscular cuff was evident at the mid thigh for several days after operation

Case 12, R. B., was a 17-year-old male with paralytic right leg shortening of 2 inches that was equalized on August 7, 1957, with 9 days' hospitalization. The pin was removed on June 18, 1958. Figures 7 and 8 show the correction.

SUMMARY

Leg-length equalization by femoral shortening of the longer extremity and intramedullary pin fixation has been without serious complication in 12 cases and has allowed brief hospitalization with early ambulation.

The procedure seems to offer more definite correction and less risk than other current approaches to the problem.

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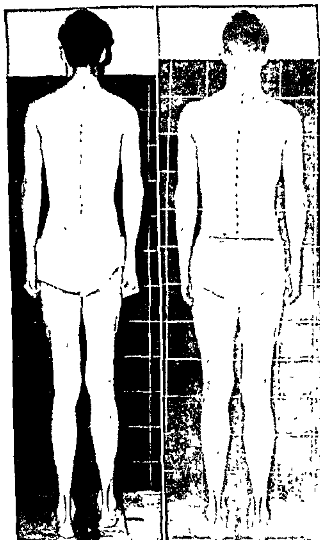
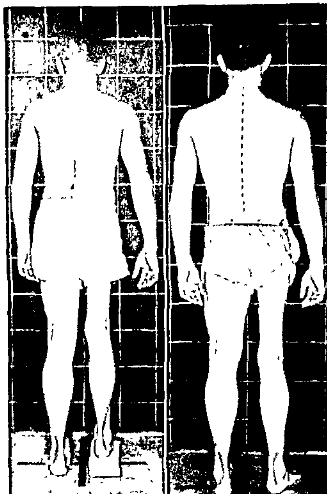


FIG. 6. B.H. Before and after equalization.



FIGS. 7 and 8, R.B. FIG. 7. Before and after operation.

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Equalisation del Longor del Gambas per Accurtamento del Femore

Summario in Interlingua

Curtitate de un gamba amontante a plus que 2 cm es melio equalisate in nostre experientia per le simple resection del altere femore in le tertio central con fixation intramedullari per medio de un clavo Hansen-Street de section rhomboide a grande calibre con helices a ambe extremitates pro facilitar le insertion.



FIG. 8. Farill-type leg-length roentgenograms before and after equalization.

Supporto de peso con crucias, quasi immediatemente post le operation, ha reducite le duration del sojorno al hospital. In adolescentes, nulle altere technica special esseva requirite pro prevenir rotation. Le clavo es facilemente eliminate post le completion del soldage. Isto ha occurrite sin incidente.

Accesso posterolateral con sterile tourniquet inguinal e le uso del serra reciprocante de Stryker ha permittite accelerar le operation. Precoce permission de activitate ha permittite le retention de un normal function del genu e un rapide accurtation del quadricipite con retorno de poter.

24

Repair of Digital Nerves in Lacerations of the Hand and the Fingers*

MICHAEL L. LEWIN, M.D.

Lacerations of the palm and the digits are among the injuries encountered most frequently in industry and the home. In the distal part of the palm and over the digits, the digital nerves are located superficially; thus, they are easily severed in injuries that may appear to be insignificant. In more extensive lacerations in which the flexor tendons are damaged, one or more of the adjacent digital bundles (the nerve with accompanying artery) usually are severed.

In the distal part of the palm, the nerves are purely sensory. The last motor components of the two volar nerves lie behind, in the proximal part of the palm. Occasionally, in deep lacerations at the base of the thenar, the short motor branch of the median nerve may be injured, together with the adjacent digital nerves. Isolated injuries of the motor branch of the ulnar nerve are rare because the nerve runs in the deep mid-palmar space, protected by the overlying structures.

Severance of a single proper digital nerve results in anesthesia of one half of the finger, while the injury of the common digital nerve results in anesthesia of half of each of the two adjacent fingers. More extensive lacerations across the palm or the digits are likely to involve several digital nerves.

Often, digital nerve injuries are overlooked or left unattended at the time of the injury. The sensory loss is not apparent unless the patient mentions it or the surgeon looks for it.

Many misconceptions of digital nerve injury still prevail. For example, the resultant disability is inconsequential; sensation returns spontaneously; the nerves are too small to be sutured.

When the nerve is severed, there is a complete anesthesia in its field of distribution, distal to the injury. If left unattended, the nerve fibers of the proximal fragment will grow out. If the two ends remain in close approximation, some of the fibers may find their way into the distal segment, and some degree of regeneration may take place. However, such spontaneous recovery is very uncertain, is dependent on almost ideal conditions, and is always incomplete. The proximal fibers reach out and embed themselves in adjacent tissue, particularly when a gap exists between the severed segments. The proliferation of the proximal ending results in a neuroma. Because of its superficial location, such a neuroma is painful on pressure and disabling. (Fig. 1) After a prolonged period some spontaneous improvement may take place, due to the overlap from the adjacent unaffected areas. But this, again, is very incomplete and limited only to the recognition of coarse sensory stimuli.

The disability in digital anesthesia has been poorly appreciated because its evalua-

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The author is indebted to Dr. Julian Rosenthal, Department of Physical Medicine, Montefiore Hospital, for all the testing in connection with this work



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Often, digital nerve injuries are overlooked or left unattended at the time of the injury. The sensory loss is not apparent unless the patient mentions it or the surgeon looks for it.

Many misconceptions of digital nerve injury still prevail. For example, the resultant disability is inconsequential; sensation returns spontaneously; the nerves are too small to be sutured.

When the nerve is severed, there is a complete anesthesia in its field of distribution, distal to the injury. If left unattended, the nerve fibers of the proximal fragment will grow out. If the two ends remain in close approximation, some of the fibers may find their way into the distal segment, and some degree of regeneration may take place. However, such spontaneous recovery is very uncertain, is dependent on almost ideal conditions, and is always incomplete. The proximal fibers reach out and embed themselves in adjacent tissue, particularly when a gap exists between the severed segments. The proliferation of the proximal ending results in a neuroma. Because of its superficial location, such a neuroma is painful on pressure and disabling. (Fig. 1) After a prolonged period some spontaneous improvement may take place, due to the overlap from the adjacent unaffected areas. But this, again, is very incomplete and limited only to the recognition of coarse sensory stimuli.

The disability in digital anesthesia has been poorly appreciated because its evalua-

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Fig. 1. Mid-palmar lacerations in industrial accident. The skin was sutured in the plant's clinic, and the patient returned to work after a week. One month later, the patient complained of inability to use his hand. Diagnosis of severance of the common digital nerve was easily established. "X" shows the location of the neuroma, which was sensitive to pressure, and the patient could not hold anything in the palm. The area of numbness on the middle and the ring fingers and of diminished sensation on the palm is marked This numbness made the use of the involved fingers awkward.

tion is based primarily on subjective findings. That this disability is a serious one can be demonstrated readily by functional tests in which the patient picks up and recognizes small objects, sews, ties a knot, winds a watch, or buttons a shirt. The speed, automatic ease, co-ordination and precision of many functions in our daily lives and in industrial skills depend to a large extent on the highly developed tactile gnosis in our fingers Furthermore, other modalities of sensation, such as differentiation between hot and cold, and between blunt and sharp, protect the fingers from burning, cutting and crushing trauma

Digital anesthesia limited to one finger or a part of it, though not as severe as a sensory loss from nerve injury in the forearm, which affects a major part of the hand, is a source of annoyance, discomfort and disability. When the radial digits are involved, the handicap may be serious, since most of our stereognostic recognition comes via the pulp of the thumb and the index finger, which is richly endowed with sensory endings.

DIAGNOSIS

Often, the patient will volunteer the information that his finger is numb. But he is likely to be more impressed by the brisk, though short-lived, hemorrhage usually accompanying such injury and may attribute the numbness to the pain and the shock of the trauma. He is further confused by the distribution of the numbness, which may be limited to half a finger.

The diagnosis can easily be made by testing the fingers with a light pinprick and by questioning the patient. Pressing or squeezing the finger is not a valid test, since such impulses may be transmitted in the absence of cutaneous sensation.

In a child or in an un-co-operative patient who does not respond to questioning, a nerve injury must be suspected if the location and the extent of the wound are considered in relation to the topography of the digital bundles. In such cases, when the wound is repaired, the nerves should be visualized and, if they have been severed, should be sutured. Objective tests of sensation are valuable in special cases but are rarely essential for establishing a diagnosis. They are not practical in acute cases. (Fig. 2)

SURGICAL ANATOMY

Detailed anatomy of the nerve supply of the hand, innervation of the intrinsic musculature and the various common deviations

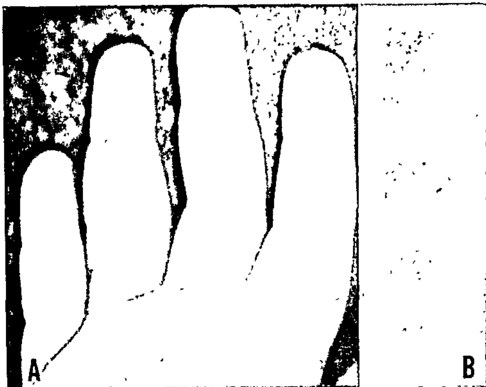


FIG. 2. (A) Scar on ring finger of 4-year-old child (as indicated by dark line) due to lacerations that occurred 2 months previously. At time of repair of laceration, severance of both digital nerves was suspected because of location of wound. The radial digital nerve was intact, but the ulnar digital nerve was severed and was sutured. Both flexor tendons were severed, and no attempt was made initially to repair them. (B) Normal sweat-gland pattern of ring finger indicating recovery of sensation 2 months after nerve suture, when flexor tendon graft was performed.

in distribution can be found in any textbook of anatomy of the hand.[2] The following, therefore, is only a brief review of anatomic facts pertinent to this discussion.

Of the three nerves participating in the sensory distribution of the hand, the most important is the median, because of the fact that it supplies the radial two thirds of the

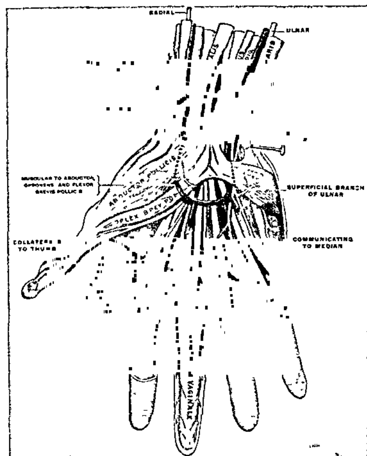


FIG. 3. Anatomy of the nerves on the volar surface of the hand and the digits. The common deviation is the prevalence of the median or the ulnar nerve. (Lewis, W. H. [Ed.]: Gray's Anatomy, Philadelphia, Lea & Febiger)

palm. Before the median nerve enters the carpal tunnel, it gives off the palmar branch (Fig. 3), which supplies the skin of the palm. The median nerve then enters the palm at the distal border of the carpal ligament at the point that roughly can be located at the intersection of the thenar skin crease and an imaginary line running from the apex of the first digital cleft to the front of the pisiform prominence. Immediately upon penetrating the palm, the nerve divides in rapid succession into several branches. The first and the shortest on its radial side is the recurrent motor twig that penetrates the thenar musculature. The radial digital nerve to the thumb branches off next. The rest of the nerve forms three common digital nerves. The first one gives off the ulnar branch to the thumb and then continues as the radial digital nerve to the index finger, in close relation to the adjacent lumbrical muscle. The other two common digital nerves pass underneath the superficial volar arch and, accompanied by the digital arteries, run just below the palmar aponeurosis, in the loose tissue between the tendons. Both digital nerves to the thumb first run parallel to each other on the anterior surface of the adductor muscle. The radial nerve then crosses the tendon of the flexor pollicis longus to reach the corresponding side of the thumb.

The bifurcation of the common digital nerves usually can be located about ¾ inch distal to the interdigital skin webs, where the nerves are covered by a fat pad. The proper digital nerves pass under the interdigital natatory ligaments and enter the soft-tissue pad of the fingers, where they run superficial to the tendons. The digital arteries can be found posterior to the nerves. The nerve can be followed to the distal finger crease, where it breaks up into terminal twigs that supply the pulp of the fingers. While the caliber of the nerve diminishes in its distal course, in the mid finger, the nerve is still big enough to permit suturing.

The course of these branches can be plotted by drawing a straight line from the point of entry of the median nerve into the palm toward their final destination. Except for supplying the two radial lumbrical muscles, all the common digital nerves are purely sensory.

The ulnar nerve enters the palm on the top of the carpal ligament, along the radial border of the pisiform bone, which is an easy surface landmark. Before reaching the distal border of the carpal ligament, it divides into two branches. The motor branch penetrates the hypothenar musculature and dives into the depth of the palm posterior to the tendons, where it runs through the midpalmar space to the first interdigital cleft. The superficial sensory branch can be found over the hypothenar eminence, covered by the palmaris brevis and a fat pad. There it gives off a palmar branch and another branch that runs on the top of the abductor digiti quinti, toward the ulnar side of the little finger. The remaining nerve forms the common digital nerve to the adjacent halves of the ring and the little fingers.

The dorsal sensory branches from the ulnar and the radial nerves leave the main stem in the distal forearm, emerge through the fascia around the wrist, and divide into multiple branches over the proximal part of the dorsum of the hand.

PROCEDURE

It is always preferable to suture a severed digital nerve during repair of an acute laceration, though this can be performed as a delayed, elective procedure. In lacerations, the nerve usually is divided without loss of substance; and, since the divided fragments do not retract as tendons do, usually they can be found close to the point of injury.

In operating on the hand, a bloodless operative field, achieved by application of a tourniquet, is desirable and may be essential. The usual application of the tourniquet on the upper arm will require general anesthesia or brachial block. On the finger, applying the tourniquet to its base may be adequate and will permit the use of local

anesthesia by blocking the appropriate digital nerves at the bifurcation and combining it with a circumferential infiltration. The injection is made through the dorsum rather than through the tough palmar skin and fascia. Less than 5 cc. of 2 per cent Xylocaine without epinephrine or an equivalent local anesthetic is needed.

A binocular loop is very helpful in identifying the small nerves and examining the cut ends. By visualizing the nerve bundles, the nerve can be identified properly, and any damaged or scarred portion can be trimmed accurately.

In acute lacerations, the wound is treated in a routine manner by irrigation and conservative débridement. Then the wound edges can be retracted or the wound enlarged, if necessary, to permit careful inspection. In the digit, the nerve can be located by blunt dissection with a pointed artery clamp in the soft-tissue pad just superficial and lateral to the flexor theca. When located, the nerve endings are eased out to obtain a slight slack before suturing. In the digit, it is preferable to enlarge the wound along the mid-lateral line, in order to approach the nerve along its course.

If a tendon repair or graft is planned as a delayed procedure, the nerve can be reached through the same exposure, and the nerve suture can be postponed justifiably.

In the palm, the fascial wound laceration may need to be enlarged. The common digital nerves are sufficiently large and, located in the loose tissue, offer no difficulty in identification and exposure. If the nerve is severed cleanly, no part of it need be sacrificed, and the fragments can be approximated. If the severance is untidy, the ends must be excised until normal nerve tissue is visible.

In the secondary repair, the elective incisions usually are mid-lateral on the finger or parallel to the creases in the palm. When the severed nerve is embedded in scar tissue, the proximal and the distal fragments are exposed where they are normal in appearance and in location. Then they are dissected toward the site of the injury. The neuroma and the scarred ends are trimmed until normal nerve bundles can be visualized. Usually it is necessary to mobilize the nerve fragments sufficiently to overcome the gap. Gentle traction can help overcome such small gaps so that the severed ends lie in approximation before the suture is undertaken.

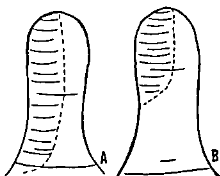
The severed nerves are approximated with the finest silk available on atraumatic needles. (Conjunctival or arterial sutures are recommended.) These sutures pass through the nerve sheath only, and an exact end-to-end approximation is obtained in order to keep the growing nerve fibers within the confines of the sheath. In the mid finger, two sutures may be all that are needed. Where the nerve is larger, several sutures are inserted circumferentially.

Occasionally, when the digital nerve is severed at the bifurcation, it may be necessary to join two small distal fragments to a single larger proximal segment. This can best be accomplished by aligning the two smaller fragments, joining them with one suture passed through the sheaths and then treating them as one unit in making the end-to-end anastomosis.

Loss of nerve substance rarely occurs in lacerations. When there is a substantial gap between the nerve fragments, it may be necessary to mobilize the nerve in the forearm to permit advancement of the proximal fragment several centimeters; or a graft from a cutaneous nerve may be used to bridge the gap. The details of this technic are beyond the scope of this chapter.

It is best to place the sutured nerve in the normally vascularized soft tissue away from the scar. If there is loss of integumental tissues, it may be necessary to cover the nerve with a skin flap, preferably one from adjacent skin. Application of a free skin graft directly over a nerve is not recommended.

Postoperative immobilization is accomplished by splinting, keeping the adjacent



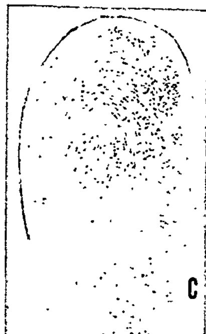


FIG. 4. Lacerations at the base of the thumb. Numbness of one side of the thumb was reported immediately. The nerve was sutured during repair of laceration. There was no sensory return on subjective and objective testing 5 months after injury. On re-exploration, the distal nerve segment was found to be sutured to a thrombosed artery. Secondary nerve suture was then performed. (A and B) Area of anesthesia at the time of the secondary operation and 1 month later. (C) Three months later, normal response to pin prick was elicited. In an electric test, the thumb showed normal response. Fingerprints on iodine starch paper revealed an almost normal sweat gland on the involved side of the thumb. Note that on the ulnar side of the thumb the density of the dots (each representing an active sweat gland) is less than on the radial side. Careful testing for tactile recognition showed that it was present but still below normal.

joints in flexion to slacken the sutured nerve. The immobilization is maintained for 3 weeks; the nerve junction then is strong enough to permit motion.

The patient is told that recovery will be slow and that the numbness will remain unchanged for a few months. Frequently, the return of sensation is preceded by a period of hyperesthesia that may be quite annoying.

RESULTS

Since digital nerves are purely sensory and are relatively close to their endings, the result of their repair is more gratifying and complete than that of any other severed nerve. The growth rate of the nerve fibers from the suture site has been estimated at 1 mm. per day—about 1 inch per month.[1,2] The anesthetic area shrinks gradually in a distal direction. (Fig. 4) The degree of sensation continues to improve for several more months. The advance of the regenerated fibers often can be followed by Tinel's sign. (Tapping over the course of the nerve elicits tingling or light shock at the tip of the finger.)

It is difficult to evaluate the completeness of sensory recovery, since digital sensations are manifold. The sense of touch and discrimination between sharp and dull usually *return within the anticipated period,* followed closely by temperature recognition. Tactile gnosis lags behind considerably.

Objective tests of sensation are based on the fact that the regeneration of the secretory sympathetic fibers that accompany the sensory nerve parallels that of the sensory component.[4] The sweat glands are inactive in denervated skin, and the absence of perspiration accounts for the smooth, velvety texture of the insensitive areas. Dryness decreases the conductivity of the skin to electric current; this is the principle underlying electric testing of sensory loss. The test can be performed better when the patient is perspiring. Normally innervated areas offer a yardstick for comparison.

Other tests, based on the absence of or decrease in sweat, utilize a fingerprinting method with the aid of substances that react chemically with sweat, such as iodine and starch, or ninhydrin. These tests show quantitative differences and are helpful in determining the degree of recovery. (Fig. 5)

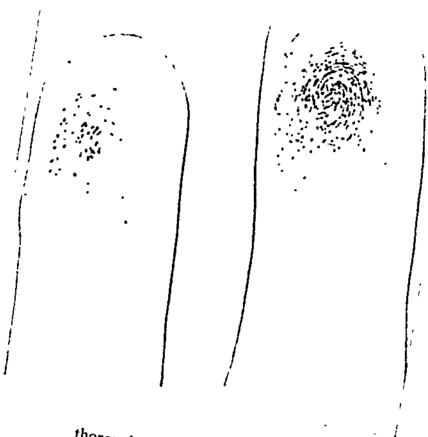


FIG. 5. Typical sweat-gland pattern in severance of one digital nerve (radial side of ring finger) as compared with normal one (middle finger).

SUMMARY

Digital anesthesia, however small the area involved, is a disability that should not be minimized. Possible injury of the digital nerves should be considered in all lacerations of the palmar surface of the hand and the digits. The diagnosis of such injury usually can be established by a simple clinical examination.

It is preferable to suture the severed nerve during the initial repair of lacerations, but it is almost equally effective as a delayed elective procedure Digital nerves can be sutured as far distally as the middle phalanx After thorough and careful nerve suture, complete sensory recovery may be anticipated.

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Reparo de Nervos Digital in Lacerationes del Mano e del Digitos

Summario in Interlingua

Anesthesia digital, mesmo quando le area afficite es micre—es un invaliditate que non merita esser considerate como neligibile. Le sensation digital es un phenomeno complexe que consiste de multe modalitates. Recognition tactile, particularmente in le digitos al latere radial del mano, es essential in omne activitate manual. Possibile vulnerationes

del nervos digital debe esser prendite in consideration in omne casos de laceration del superficie palmar del mano e del digitos.

Le diagnose de tal vulneration pote, usualmente, esser establite per un simple examine clinic: On testa le digitos per un leve piccatura de agulia e accepta le responsa subjective del patiente. Tests objective de sensation es basate super le function de glandulas sudoripare. Istos es absente quando le nervo es secate. Le pelle sic revela un augmento de resistentia in tests con currente electric. Per medio de un methodo de impressiones digital in combination con le uso de substantias chimic que reage con sudor, le absentia o diminution de activitate sudoripare pote etiam esser demonstrate. Iste tests es utile in le caso de patientes pediatric o de patientes non-cooperatori e in le evalutation quantitative del sensation.

Il es preferibile suturar le secate nervo durante le reparo initial del laceration, sed iste operation es quasi equalmente efficace quando illo es executate como un retardate manovra elective. Nervos digital pote esser suturate in areas distal usque a illo del phalange medie. Post le meticulose e precise sutura del nervo, un complete restablimento sensori pote esser expectate.

25

Small-Element Lesions of the Cervical Spine Due to Trauma

RICHARD F. WAGNER, M.D., AND MARTIN S. ABEL, M.D.*

Major sources of neck injury are (1) blows to the head, transmitting force to the neck, and (2) sudden application of force to the body with the head unsupported on the flexible neck. This is the so-called whiplash that is so common in crash injuries. The very complexity of the bones, the joints and the soft parts traumatized renders accurate diagnosis difficult.

X-ray helps to separate the bony from the soft-part lesions. Review of the literature shows progressive striving for improvement in diagnostic technics over the old anteroposterior and lateral views, which proved

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The authors are indebted to the anatomy department of the Medical School, University of California, at Berkeley, for their co-operation and the use of their facilities; to Dr. C. W. Asling, professor of anatomy of the Medical School, University of California, for his personal aid and his suggestion for the application of microradiography to this project; and to the x-ray department of Stanford University Hospital and the Alameda County Tuberculosis Association for the use of the chest roentgenograms.

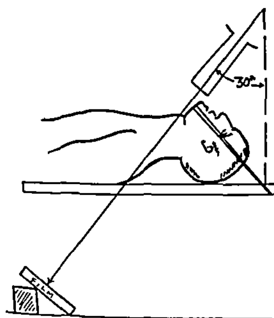




FIG 1. The anteroposterior angled 30° caudad view. (*Left*) Positioning diagram The technic shown includes the magnification technic, which is optional. The angle may be changed slightly for individual cases. (A M.A. Scientific Exhibits 1957, New York, Grune) (*Right*) Normal cervical spine. Note the symmetric visualization of the lower laminae, facets and lateral masses.

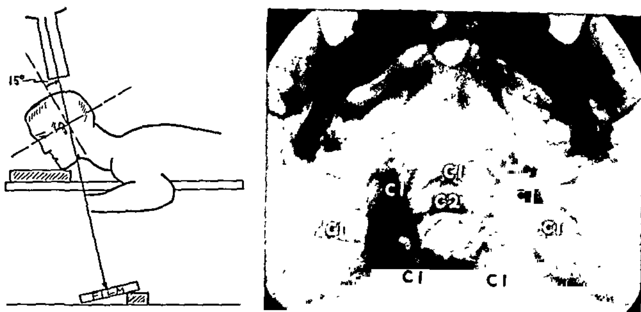


FIG. 2. The modified occipitosubmental view of the upper cervical vertebrae. (*Left*) Positioning diagram. The magnification shown is optional. The angle may be varied slightly in individual cases. (*Right*) Normal example. Note the axial view of the entire ring of C 1 and the excellent visualization of the transverse processes of C 1. (A M.A. Scientific Exhibits 1957, New York, Grune)

to be so sadly inadequate on autopsy check.[12] Oblique views, the flexion-extension laterals of Davis,[11] views taken in traction to show ligamentous tears[7] and, recently, Boylston's flexion-extension obliques[8] have been added to the standard views. This last-mentioned technic demonstrated lateral interarticular isthmus and laminar fractures, later confirmed at surgery.

For some years the authors have adopted additional views of the cervical spine based on anatomic studies in cadavers.[2-4]

For visualization of the apophysial joints, the interarticular isthmi and the laminae of the lower spine, a 30° caudad angled anteroposterior view is invaluable, showing the joints, the isthmi and the laminae in symmetric fashion (Fig. 1). This is best taken stereoscopically. For the atlas and the axis, a modified occipitosubmental view, similar to that advocated by Jackson, is best.[14] This also is done in stereo (Fig. 2). For best visualization of the Luschka joints, the anteroposterior view angled 20° cephalad is recommended (Fig. 3).

In addition, we feel strongly that use of the 0.3 mm. focal spot x-ray tube gives films of better diagnostic quality. This is especially true in the occipitosubmental view of C 1, where the part is necessarily some distance from the film, and good bony detail is a rarity with larger focal spots. A short tube-object distance is employed with these three views and the oblique views, producing differential magnification and separation of superimposed shadows.[1-4] Note in Figure 1, *right*, the absence of a superimposed shadow of the vertebral body over the posterior elements.

These technics were found to be adequate for the diagnosis of small fractures produced in cadavers by forces simulating whiplash injury.

These same lesions, plus subluxations, are demonstrated in the clinical series. In order of frequency our patients disclosed:

(1) interarticular isthmus fractures with or without laminar involvement (Fig. 4)

(2) fractured transverse process of C 1,

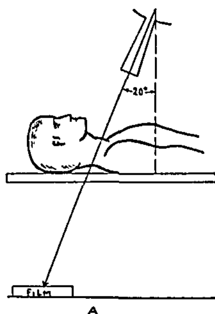




Fig. 3. Anteroposterior view angled 20° cephalad. (*Left*) Positioning diagram. The magnification technic demonstrated is optional. (*Right*) Normal example. Note the symmetric visualization of the joints of Luschka.

frequently extending into the articular facet (Fig. 5)

(3) rotational subluxations of C 1 with respect to the occiput and the axis.

This diagnosis is sometimes difficult to make when the head is twisted, but we feel that unequal placement of the right and the left facets of the atlas on the occipital con-



Fig. 4. M.P., 56-year-old male Whiplash injury sustained on July 23, 1956 (*Left*) Anteroposterior caudad view on July 24. Note slight deformity superior facet C 6, left (*Right*) Anteroposterior caudad view on December 6. Note further sagging and fragmentation of superior facet in intervening 5 months. (A.M.A. Scientific Exhibits 1957, New York, Grune)



Fig. 5. M.P., 29-year-old female, who was in a head-on collision on September 9, 1955. (*Left*) Occipitosubmental view on September 23. Note avulsion, fragmentation and rotation in two planes of left transverse process of C 1 (not visible on open-mouth view). (*Right*) Occipitosubmental view on November 8, 1956. Note improvement in position of fracture fragments and new bone formation in intervening year. (A.M.A. Scientific Exhibits 1957, New York, Grune)

dyles in the occipitosubmental projection is a quite reliable criterion (Fig. 6).

(4) Luschka joint fractures (Fig. 7).

CLINICAL EXAMINATION

In reviewing reports of examinations of individuals subjected to neck trauma, one is struck by the frequent incidence of vague description of symptoms and such generalizations as "the neck shows a good range of motion." In many instances, an initial examination will demonstrate a range of motion that would be within the average limits of normal, and only subsequent careful examination will show that in this particular patient there was actually a limitation to begin



Fig. 6 H F., 46-year-old male, who was in a rear-end collision on January 10, 1957. (*Left*) Occipitosubmental view on March 16. Note rotation of C 1 with respect to the occipital condyles anteriorly on the right and posteriorly on the left. (*Right*) Roentgenogram of occipitosubmental view of C 1 dated March 25 after traction and manipulation under anesthesia Note reduction of rotary subluxation seen on previous roentgenogram



FIG. 7. I.B., injured on July 10, 1955, in an automobile-motorcycle collision. (*Left*) Lateral view. Note sliver of bone off inferior cortex of C 6 extending anteriorly from joint of Luschka. (*Right*) Anteroposterior view angled cephalad December 16, 1956. Note fragmentation of sixth Luschka joint. (A.M A. Scientific Exhibits 1957, New York, Grune)

with. Therefore, careful questioning, careful observation and measurement and, above all, an open mind are indispensable in the evaluation of these cases. It is strongly suggested that the clinical examination include the taking of the history by the examining physician himself, as well as careful inquiry as to the mechanics of the injury, presence of neck pain, occipital headache, visual disturbance and/or periorbital pain, shoulder girdle and/or arm pain, and sensory disturbances in the above-mentioned areas. Also, the presence of dyspnea or dysphagia should be sought.

Physical examination should cover the following:

(1) Testing of range of motion in flexion, extension, right and left flexion, and right and left torsion, measurements being made with a goniometer. Only thus can serial examination indicate the presence or the significance of limited motion. Pain or absence of it at extremes of motion should be recorded, and, in later examinations, crepitus on motion should be sought.

(2) Investigation of involuntary muscle spasm by palpation of the superficial muscles with the patient relaxed.

(3) Investigation of point tenderness, not only by the usual percussion and palpation of the spinous processes, but with the patient prone, his head supported on pillows or on the examiner's lap, so that C 1 and C 2 tenderness, which is difficult or impossible to elicit in the upright position, may be demonstrated.

Also, lateral tenderness should be sought by palpation anterior to the trapezius border with the patient seated and the head sup-



FIG. 8. Physical examination of the neck. (*Left*) Palpation posteriorly of the C 1-2 area. Relaxed head, face supported by pillow. (*Center*) Examination for tenderness laterally by palpation anteriorly to the trapezius border with the head supported by the examiner from behind. (*Right*) Examination in the upright position with the cervical muscles relaxed by supporting the chin on the examiner's hand, which rests on the patient's manubrium.

ported by the examiner from behind. The usual examination of the spinous processes for tenderness may be made simpler by supporting the patient's chin against the examiner's fist with the fist on the suprasternal notch. (Fig. 8)

(4) Neurologic examination, including sensory examination of the head, and testing of the pupillary reflexes with particular search for Horner's syndrome and measurement of pupils at extremes of cervical torsion. These findings indicate stretch or other injury of the cervical sympathetic chain.[7]

Nerve trunks should be palpated for tenderness.

(5) Inspection of the pharynx for the presence of retropharyngeal hematoma.

CLINICAL SERIES

In an attempt to discover the significance of occult fractures and subluxation of the types demonstrated by Boylston and Abel, a series of 100 unselected cases showing occult lesions radiologically was analyzed and compared with a similar series of cases in which the roentgenograms failed to demonstrate such injuries. We emphasize that this *is not an end-result study, since the follow-*up is too variable, and the series is too small for statistical analysis. Indeed, some of the radiologic technics used in this study are less than 5 years old. However, in making the comparison, certain trends become apparent.

The series of 100 cases showing occult fractures had follow-up from 3 to 37 months. This series included 48 interarticular isthmus and laminar fractures of lower cervical vertebrae. One case was associated with a Luschka joint fracture. There were 20 cases of fracture involving the transverse processes of the atlas or the axis, in some *instances extending into the joints.* There were 31 cases of combined lesions from these two previous categories in the same patient. There was one pure Luschka joint fracture. In addition to this, 36 cases of rotational deformity of C 1 are included in this series, each case associated with one of the fractures enumerated above. (This lesion is also present in the control series unassociated with fracture.)

The following clinical observations are made:

1. Neck pain was present in all cases.
2. Occipital headache was present in 81 cases of the 100, including many of the pure *lower cervical fracture lesions,* but was present in all but three of the atlas axis fracture

group and seemed to be of greater duration in this group.

3. Cerebral symptoms correlated with upper cervical lesions. These consisted of blurred vision, difficulty in focusing, trouble with balance, and orbital pain.

The importance of disturbance of the suboccipital muscles and the righting reflex mechanism in which they play so important a role has been pointed out by Campbell.[9] Skillern,[18] Seletz[17] and Jackson[15] have indicated the importance of involvement of the second cervical root in production of these symptoms and its anastomosis with the ophthalmic branch of the trigeminal nerve in the brain stem, through the tract of the descending V.

Jackson has stressed the peculiar vulnerability of the second cervical root, in that it is unprotected either by facets or lamina, though lying adjacent to the most mobile cervical joint.

Fielding,[13] in his cineroentgenographic studies, has demonstrated beautifully the extreme and complex motion of the atlanto-axial joint.

In our fracture series, where the lesions were localized in the lower cervical region, these and similar symptoms were recorded only in those cases complicated by concussion.

4. Shoulder and arm symptoms appeared to be indicative of lower cervical lesions; they were present in 25 of the 48 pure lower lesions, in 21 of the 31 combined upper and lower lesions, and in only one case where there was a pure upper fracture.

5. Limited motion in one or more planes was present in all cases and usually improved on serial clinical examination.

6. Involuntary muscle spasm was elicited in the acute postinjury stage in all patients. With patients in the upright position, habit-protective muscle-guarding persisted in many cases for long periods, but, because of difficulty in differentiating this from voluntary spasm, it was hard to evaluate.

7. Localized bony tenderness proved to be the most reliable sign of fracture coinciding with areas of x-ray deformity in a large majority of cases. In patients seen very early after injury, tenderness was less well pin-pointed than in those seen a few days later.

8. Neurologic examination rarely revealed positive signs in spite of the multiplicity of symptoms suggestive of nerve root irritation. There were 11 cases of hypesthesia involving root areas adjacent to the fracture site, 10 brachial, 1 cervical. A diminished reflex occurred in 3 cases, 1 persisting 3 years.

For control, a similar group of neck injury cases not involving fracture was examined for comparison with the 100 cases cited above. Sixteen per cent of these cases showed rotational deformity of C 1. Neck pain was a complaint in all cases, but additional symptoms occurred in lesser incidence. For example, occipital headache was seen only in 36 per cent; eye symptoms or orbital pain, in 10 per cent; shoulder girdle or arm pain, in 14 per cent. Physical examination revealed limited motion in one or more planes in all cases and involuntary muscle spasm in the acute stage in all cases. Well-localized bony tenderness was present in 38 per cent of cases, and 3 per cent showed hypesthesia. No reflex abnormalities occurred. Certain factors are compared in Table 1.

The above figures indicate that no single clinical finding is pathognomonic of fracture but that well-localized bony tenderness and the presence of other symptoms in addition to neck pain are certainly suggestive. Comparison of the two series of patients with cervical trauma with or without fracture showed a considerable amount of overlapping of duration and severity of symptoms, but a number of trends was obvious:

1. Examining the table, it can be seen that neck pain and limitation of motion lasted, on the average, almost three times as long in those with demonstrable fracture as in those without.

2. Localized bony tenderness was present

TABLE 1. PATIENTS WITH INDIRECT CERVICAL TRAUMA

	WITHOUT FRACTURE (100 CASES)	WITH FRACTURE (100 CASES)
Age	18 to 66, av. 35	12 to 60, av. 36
Neck pain	½ to 12 mos., av. 3.4	1 to 37 mos., av. 11.1
Lim. motion	¼ to 12 mos., av. 2.3	1 to 37 mos., av. 8.3
Spasm	Few days to 1 mo., av. 0.8	1 to 7 mos., av. 1.15
Bony tenderness	38% well localized	86% well localized (fractured and adjacent vertebrae)
Arm symptoms	14%	47% (largely in lower lesions)
Eye symptoms	10%	12% (largely in upper lesions)
Rotation C 1	16%	36%
Duration of care	1 to 18 mos., av. 4.3	2 to 37 mos., av 12.3

in over twice as many of those with fracture as those without.

3. Referred pain down the arm from lower cervical lesions was present in more than three times as many cases where lower cervical fractures were present.

TREATMENT

Since the presence of these fractures is a new thing in diagnosis, the treatment is more or less empirical and based on common sense treatment of combined soft part and fracture lesions elsewhere. The program advocated consists of bracing and local heat for the first 3 weeks. At the end of this time, it is considered that there has been sufficient healing of soft tissues to warrant the addition of cervical traction. This is *quite gentle at first and is increased to tolerance*. Intermittent mechanized traction is felt to be superior, since it permits the patient to take greater forces, and normal vertebral realignment may be established by this means alone. Earlier use of traction is contraindicated, since it interferes with the healing of torn ligaments and other soft parts, and, of course, distraction is known to be detrimental to early callus formation.

These fractures involve small flat bones that heal at varying slow rates, and mainly by endosteal callus. In dealing with the *x-ray findings in this matter, it would appear* that a minimum time of 8 weeks is necessary to distinguish x-ray signs of osseous change consistent with healing of fresh fracture. This is the earliest that a brace may be discarded, and clinical signs are the best guide at this stage.

In some cases, as pointed out by Abel,[2] deformities have been seen roentgenographically apparently predating the immediate injury. Here clinical signs are found to disappear in a period commensurate with soft-part healing, and follow-up roentgenograms *fail to show changes characteristic of healing* fresh fracture.

After follow-up roentgenograms have been made, gradual freedom from bracing is accomplished, accompanied by a graded exercise program. Physiotherapy and traction are continued through this period so as to vary only one factor at a time. Sudden discarding of the brace usually results in increased symptoms due to cervical muscle insufficiency.

An apparent paradox is seen in those cases which heal well, in that motion is observed to increase during bracing. In a few instances, the reverse has been seen, and frequently such cases have been found to be complicated by the presence of a rotational C 1 deformity. Such cases have been treated with forceful traction and gentle rotation under general anesthesia with the addition of a muscle paralyzant. Reduction of the deformities has been recorded on x-ray as demonstrated. (Fig. 6) Following this, the patient is again braced for a time to allow for soft-part healing, and, after this, decrease

in symptoms and increase in total motion have been noted.

Adjuncts to treatment are recumbency, analgesics, antispasmodics, tranquilizers and nerve blocks. No cases have been treated with open operation.

Follow-up Studies of Fractures

Twelve cases were followed by clinical examination and roentgenograms from 25 to 37 months. The series is too small for statistical analysis.

All patients had persistent symptoms localized to the injury area on latest follow-up. Litigation had ceased to be a factor in all but one case. Four cases of work disability existed. Some patients who had normal total motion at the end of the period of active treatment later showed diminished range. In some of these, very early arthritic changes were demonstrated at injury site.

In the Luschka joint fracture, the only complaint offered was subjective crepitus. The patient was unaware of 1-inch atrophy at the left mid biceps, the deltoid and the forearm measurements being equal. The biceps reflex was diminished on the same side.

Experimental Studies and Correlation

1. In attempting to radiograph a series of normal cervical spines for reference, it was soon found that a number of asymptomatic subjects had quite marked deformities of contour and structure of smaller cervical spine elements, most frequently in the region of the lower cervical interarticular isthmi. Upon close questioning, most of these subjects could recall some traumatic episode of possible relevance, even though they had not previously given a traumatic history. These traumatic episodes were not usually of great severity, but, as shown by one of us,[3] it does not require a great deal of force to produce a fracture in this area experimentally. Actually, there are probably few people who could not recall a half-forgotten trauma to the neck.

Accordingly, it was decided that a different approach was needed, and about 3,000 lower cervical spines were evaluated, as seen on routine chest roentgenograms. This yielded 1,074 posteroanterior chest roentgenograms, on which the lateral masses of the lower two or three cervical vertebrae are seen in about the same projection as on our anteroposterior caudad angled view. This series, of course, is selective insofar as lateral masses with low degrees of obliquity only are well seen on the chest roentgenograms. The procedure is also incomplete, because it ignores lesions at higher levels. Furthermore, the bony detail on such roentgenograms is seldom good enough to recognize abnormalities of internal structure. However, it was felt that such a study would give a rough mass evaluation of the frequency of *gross deformities* and their relative frequency according to the age of the patient. The results are as shown in Table 2.

Two findings are noteworthy: the frequency is quite high, and the incidence increases with age. The conclusion is that these deformities are acquired and *not* congenital. Furthermore, the high incidence in the lower age group indicates that we are not dealing with an aging phenomenon per se; it emphasizes the probability of trauma as an etiologic factor in many cases.

2. The necks of 31 cadavers were roentgenographed, and then cleaned of soft tissues, and the bones were examined macroscopically and microscopically. The cadavers were selected at random from those used for teaching in the Anatomy Laboratory. In

Table 2. Lower Cervical Spine Survey from Chest Roentgenograms

Age Group	No. of Cases	No. Abnormal	% Abnormal
0-1	18	0	0
1-20	203	17	8.4
21-40	418	46	11.0
41-60	296	61	20.6
61 and over	139	57	41.0

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FIGS. 9 to 11. Studies of Cadaver 1. This subject fell out of bed 4 months before death, injuring his head and neck. (A.M.A. Scientific Exhibits 1957, New York, Grune) FIG. 9. Anteroposterior view angled 30° caudad shows lateral compression of right articular process of C 6 together with alteration in the internal structure of the bone in the interarticular area.

one case there was a history of the individual's having fallen out of bed, striking his head, 4 months prior to death. In the others, there was no history of significant trauma or of complaints localized specifically to the neck. Of the 31 cadavers, the one with the history of trauma had a healing fracture of the interarticular isthmus of C 6. Of the 30 with no traumatic history, 8 had definite evidence of a fracture involving the lateral mass of one of the vertebrae from C 4 to C 7. Other areas of fracture were present in lesser incidence. The diagnosis of fracture was based on the following correlated factors and criteria:

A. Evidence of deformity of contour and internal structure on the original neck roentgenograms. Variation of height of the lateral mass alone is not sufficient criterion.

B. Finding of the gross anatomic deformity upon dissection of the specimen.

C. On microscopic section, finding of gross distortion of the trabecular pattern in the area of suspected fracture. In the one case of recent trauma 4 months prior to death, fibro-osteoid tissue with cement lines was found in the involved area, indicating that the fracture was still healing (Figs. 9-12).

D. Microradiography of sections of suspected fracture in comparison with sections of normal areas showing variation of density of osteons in the area of distorted trabecu-



FIG. 10. Right and left lateral views of the gross specimen. Note the anterior displacement of the superior facet of C 6 on the right as compared with the inferior facet. This was a quite characteristic shearing deformity found repeatedly in interarticular isthmus fractures in cadavers and patients.

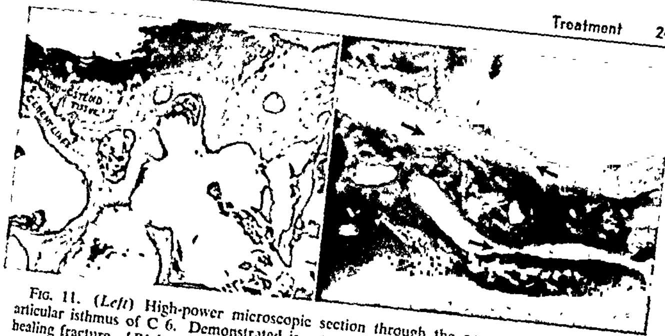


FIG. 11. (*Left*) High-power microscopic section through the compressed right interarticular isthmus of C 6. Demonstrated is osteoid tissue and cement lines indicative of a healing fracture. (*Right*) Microradiograph of bone from same area as microscopic section shows the irregularity of trabecular structure and variation of bone density indicative of the presence of new and old bone. This is the picture of regenerating bone.

lae and indicating the presence of new and old bone. (Figs. 13-15)

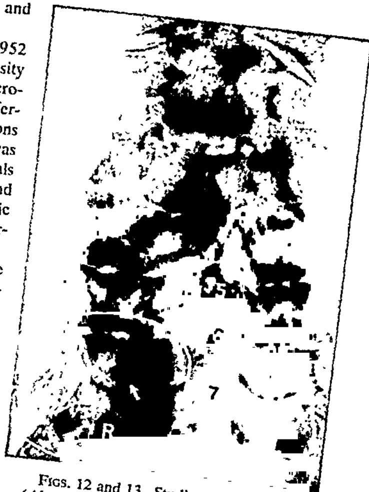
It was first shown by Amprino[5,6] in 1952 that the variations in radiographic density of haversian systems revealed by microradiography were due principally to differences in calcium salts, the younger osteons being the least calcified. This work was confirmed by autoradiography in animals by LaCroix, of Belgium,[16] in 1953, and was confirmed further by other histologic technics by LaCroix and Cohen[10] at Harvard in 1953.

In some instances we have been fortunate enough to get sections showing broken trabeculae of a good degree of radiographic density joined together by newer bone of lesser density (Figs. 16 & 17).

A consideration of these anatomic findings, together with the results of the survey of cervical spines from the chest roentgenograms, leads to the following conclusions:

a. A great proportion of these acquired lateral mass abnormalities are due to healed fractures.

b. These healed fractures may be asymptomatic, and the causative trauma may have been so trivial or ancient as to have been forgotten.



FIGS. 12 and 13. Studies of Cadaver 2. (Abel, M. S.: Am. J. Surg. 97:536)

FIG. 12. Anteroposterior view angled 30° caudad demonstrates marked sigma-shaped deformity of the superior joint surface of C 7 on the right.



FIG. 13. (*Left*) Microradiograph of bony section from normal left superior facet of C 7. Note regular pattern of trabeculae and uniform calcification with sharp borders. (*Right*) Microradiograph of bony section from abnormal right superior facet of C 7. Note the trabeculae and irregular calcification and fuzzy contour. Upper arrow points to dark bridge of new bone joining two well-calcified, fairly normal trabecular fragments Lower arrow shows small punched-out dark areas in bone. This we believe is the picture of new and old bone, normal and abnormal, representing a healed fracture.



FIGS 14 and 15. Studies of Cadaver 3. (Abel, M. S., Am. J. Surg. 97:537)

FIG. 14. Anteroposterior view angled 30° caudad shows marked lateral compression of C 6, lateral mass indicated by arrow The specimen also demonstrated the characteristic shearing and displacement anteriorly of the superior facet of the involved articular process.

c. Therefore, absence of symptomatology, a traumatic history, or both, does not necessarily indicate normalcy, and a group of such patients cannot be used as normal controls.

3. A study of arthritic changes in 31 cadavers showed that hypertrophic changes of the bodies of the cervical vertebrae occurred independently of similar changes in the facets, and vice versa.

In those cases in which there was any considerable amount of hypertrophic change of the facets there was a notable deformity of one or more of the facets with malalignment of the facets. The maximum amount of arthritic change on the ipsilateral side was at, or about, the site of such deformity with lessening degrees of change of the facets up and down from the level of the lesion. A similar focusing of arthritis occurred to a lesser extent on the contralateral side, usually concentrated at the same level or a level above the lesion.

The following conclusions may be drawn:

A. Hypertrophic changes of the bodies of cervical vertebrae are independent of changes in the smaller apophysial joints and possibly are associated with static stresses and strains.

B. Hypertrophic changes in the apophys-



FIG. 15. Microradiograph of the affected articulation shows quite clearly fairly normal, dense, trabecular fragments joined by fuzzy, irregular, dark bridges of new bone, the picture of a healed fracture.

ial joints are associated with deformities and malalignments, notably with fracture deformities in this series. These changes appear to be a response to altered mechanics in movements of the neck.

CONCLUSION

There has been presented ample clinical and experimental evidence that fractures of the smaller elements of cervical vertebrae in both the lower cervical spine and the C 1 area are quite common as the result of trauma. The use of additional radiologic views and technics is strongly urged for better evaluation of these patients.

The clinical findings indicate that on the average, the degree of symptomatology, the duration of morbidity, the frequency of associated neurologic findings, and the duration of treatment are greater in those cases of cervical trauma where occult fractures are demonstrated by roentgenogram.

Some clinical diagnostic points have been made, and the treatment of neck trauma in the absence of adequate x-ray examination should be cautious and predicated on the frequent presence of such small fractures

The final evaluation of the effect of each of these separate injuries—(1) fracture of the interarticular isthmus, (2) fracture of the transverse process of C 1 with or without involvement of the adjacent joint, (3) the Luschka joint fracture and (4) rotary subluxation of C 1—because of the difficulties attendant on diagnosis and the complication of coexistent soft-part lesions must await follow-up studies in a large series of patients over many years.

Unfortunately, the medicolegal implications of such lesions are obvious, the situation being analogous in this light to the discovery of the herniated disk syndrome some 30 years ago. A plea is made that these patients be considered objectively and that the symptoms and the residua be evaluated dispassionately.

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Lesiones de Micre Elementos del Spina Cervical in Consequentia de Tra

Summario in Interlingua

A parte le recentemente introducite radiogrammas *special del spina cervical in traction*, aspectos lateral de flexion con extension, e aspectos oblique de flexion con extension, le autores recommenda le uso de un aspecto anteroposterior angulate a 30 grados verso le cauda e un modificate aspecto occipitosubmental prendite con un tubo a puncto focal de 0.3 mm. e curte distantia inter tubo e objecto, durante que le uso de stereoscopia remane optional Radiogrammas special ha revelate fracturas de isthmos interarticular e de laminas del vetebras inferocervical. Avulsiones de processos transverse, sin o con affection de massas lateral e etiam subluxation rotational de C 1 es similemente visualisate. Fracturas de elementos del articulation de Luschka es visibile in aspectos standard anteroposterior que se prende le melio a un angulation de 20 grados verso le cauda. Es pres *constatationes experimental, incluse le* tation del massa de grossier deformita le spina inferocervical vidite in radio mas thoracic insimul con studios m scopic e microscopic e microradiograp cadaveres, pro provar le validitate del statationes roentgenologic. Es ponite in trasto series clinic de casos con e sin evid de fractura, e conclusiones prelimina formulate que stipula un plus grande mo tate e un plus alte frequentia de com tiones in le gruppo de casos con fractura delineate technicas special in le obtentio anamnese, in le examine physic, e in le vidualisation rational del tractamento. sublineate le importantia del immobilis durante le prime septimanas, sequite tarde per traction.

26

X-ray Projections of Anatomic Structures in the Cervical and the Lumbar Vertebrae*

RAYMOND G. TRONZO, M.D.†

Interpreting roentgenograms of the cervical and the lumbar spine are difficult without thorough knowledge of the bony anatomy. Keeping in mind the normal anatomy of vertebral structures in such interpretation :an be of great help when one is faced with case of trauma to either the neck or the w back region. Grossly abnormal verteae in themselves are obvious enough. It the subtle configurations that baffle even the experts when they must answer the question, "Is the roentgenogram that of a normal or a pathologic spine?" This is especially true of the cervical region. For these reasons, a project was undertaken to demonstrate the anatomy of the cervical and the lumbar vertebrae as projected on roentgenograms.

Lead paint was found to be the most satisfactory material radiopaque enough to outline the structures adequately on roentgenograms. It was impractical to differentiate the finer details of the vertebrae because they appeared as superimposed shadows that were of little clinical value. Therefore, in some areas only the gross parts were outlined by the lead paint.

CERVICAL VERTEBRAE

Both the atlas (C 1) and the axis (C 2) are each distinct vertebrae. The atlas is a ringlike structure composed of a narrow anterior arch with its anterior tubercle, comparable with a body. The posterior portion of the ring is made up of the posterior arch and the posterior tubercle, comparable with the laminae and the spinous process. Connecting these arches are the two "lateral masses," a term which refers to the composite of the superior and the inferior articular surfaces of the articular column and the transverse processes with their relatively large transverse foramina. The arches of C 1 are best seen on the lateral views (Fig. 4), while the lateral masses are seen best in the anteroposterior view (Fig. 2). A special anteroposterior view best suited for this is the open-mouth technic, which is not shown here per se but is comparable with that in Figure 2.

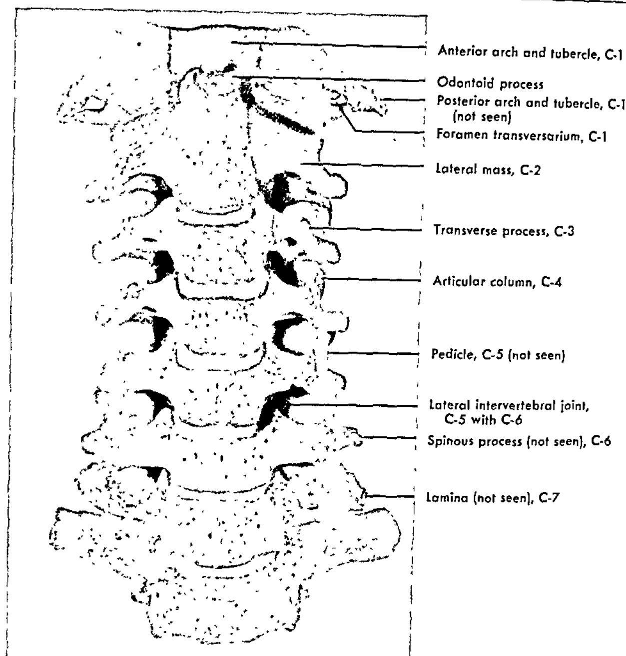
This view is also particularly helpful in demonstrating the important relationship between the lateral masses of C 1 with those of C 2, which articulate on wide horizontal surfaces; more specifically the inferior articular facet of C 1 matches evenly the superior articular facet of C 2. When there is a rotary subluxation of C 1 on C 2, or when there is a bursting fracture of C 1, this relationship is distorted.

The axis, in contrast with C 1, does have a body that has a peculiar shape

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* The author is indebted to Miss Dorothy Moore, assistant supervisor, department of x-ray technology, The Philadelphia General Hospital, for obtaining the roentgenograms in this study.

† Department of Orthopedic Surgery, The Philadelphia General Hospital, Philadelphia, Pa.



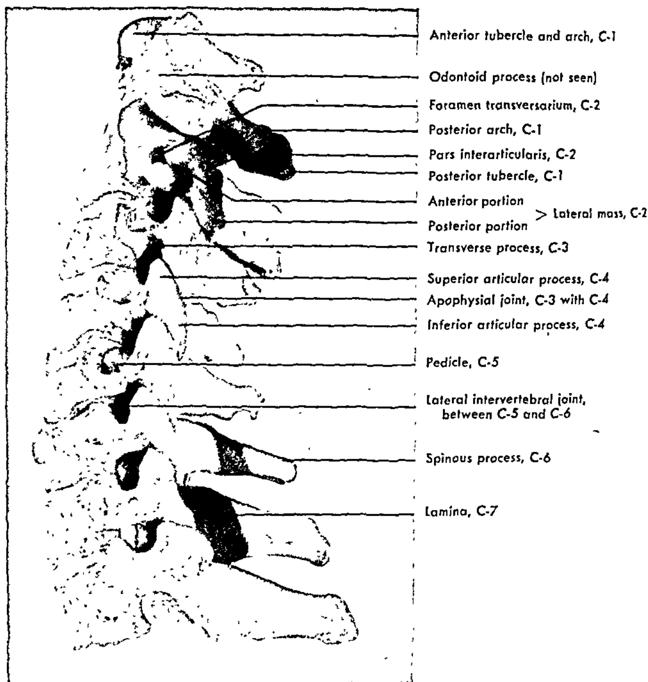
FIGS. 1 and 2. Anteroposterior projection cervical vertebrae

because of the clublike odontoid process that articulates with the anterior arch of the atlas. The open-mouth anteroposterior is also best for demonstrating the odontoid process. The lateral masses of C 2 are more elaborate. For the best radiograph[illegible] pretation, these have been [illegible] trarily into two parts: an [illegible] made up of a large superior [illegible] and transverse process, and a [illegible] tion, which is the inferior [illegible] (Figs. 3 & 4). The superior [illegible] is shifted forward on its inferior partner, similar to a lumbar vertebra. For this reason, the existence of a pars interarticularis can be assumed for C 2. In all the other cervical vertebrae, the superior articular process lies directly over the [illegible]r articular process, thus forming [illegible] column." Although a pars [illegible] for C 2 is not described any[illegible] a better description for referring [illegible] in this area than the phrase [illegible]y used "a fracture [illegible] the [illegible] C 2." For [illegible]



Anterior arch and tubercle, C-1
Odontoid process
Posterior arch and tubercle, C-1
Foramen transversarium, C-1
Lateral mass, C-2
Transverse process, C-3
Articular column, C-4
Pedicle, C-5
Lateral intervertebral joint, C-5 with C-6
Spinous process, C-6
Lamina, C-7

FIGURE 2



FIGS. 3 and 4. Lateral view cervical vertebrae.

tical purposes, a pars interarticularis is specific for C 2.

There is one other important characteristic of the axis that deserves emphasis. The transverse process of C 2 with its transverse foramen joins the two ends of its corresponding pedicle at an angle of 45°. The foramen, in turn, is tilted so that its oval contour is obvious on the lateral view (Fig. 3). Figure 13 is a reproduction of the cervical spine of a patient who sustained a fracture subluxation through the pars interarticularis of C 2 at the level of the transverse foramen. This roentgenogram was read by an experienced radiologist as a "fracture through a cyst of C 2." The cyst is the transverse foramen of C 2, which appears as an ovoid radiolucency on roentgenograms. It does not

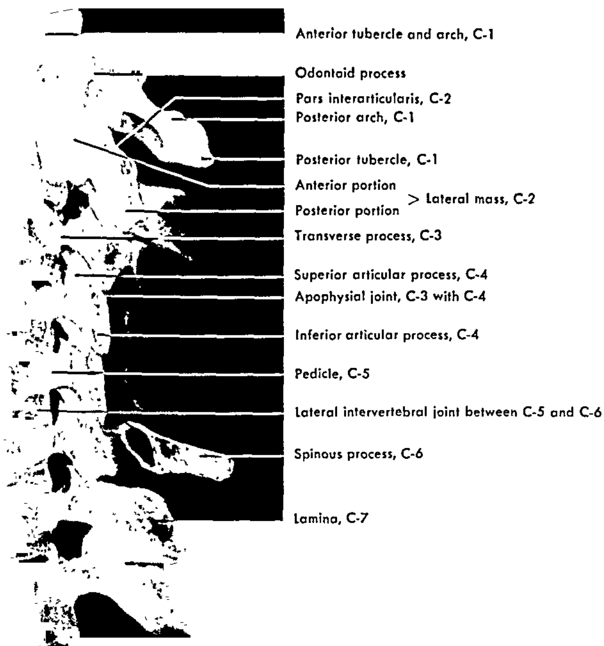
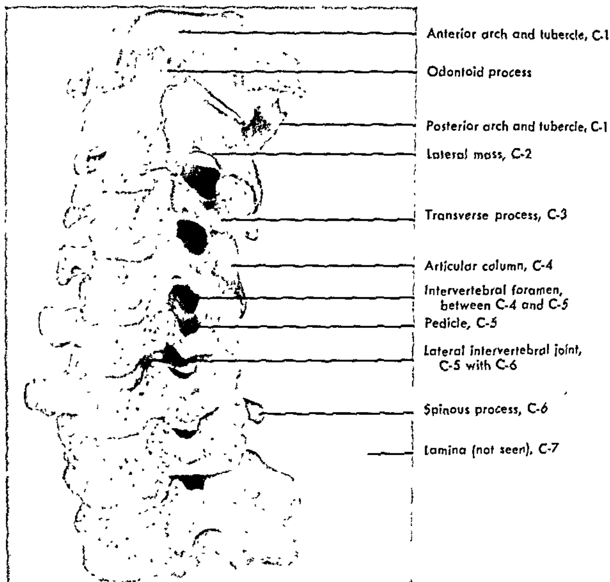

Anterior tubercle and arch, C-1
Odontoid process
Pars interarticularis, C-2
Posterior arch, C-1
Posterior tubercle, C-1
Anterior portion
Posterior portion
> Lateral mass, C-2
Transverse process, C-3
Superior articular process, C-4
Apophysial joint, C-3 with C-4
Inferior articular process, C-4
Pedicle, C-5
Lateral intervertebral joint between C-5 and C-6
Spinous process, C-6
Lamina, C-7

FIGURE 4



FIGS. 5 and 6. Left posteroanterior oblique cervical vertebrae.

always show up on lateral roentgenograms unless C 2 itself is set perpendicular to the x-ray cone. Such a condition would happen by chance. Usually the rays are centered over the mid section of the patient's neck, causing enough distortion to have the foramen obliterated by the tip of the transverse process. In the other vertebrae, this foramen is not seen because the transverse processes are angled to a lesser degree, and the bony ring around the foramen is not so massive as to give such a distinct outline as in C 2.

The transverse processes of C 3 to C 7 are gutterlike structures that protrude forward enough to be superimposed on the bodies of the vertebrae in the lateral roentgenogram (Figs. 3 & 4). When the roentgenograms are of excellent quality, there is enough definition to identify them as transverse processes. However, when there is less detail on the roentgenogram, they appear as relative cystlike defects in the bodies. They may be misinterpreted as Schmorl's nodes or as cysts secondary to degenerative

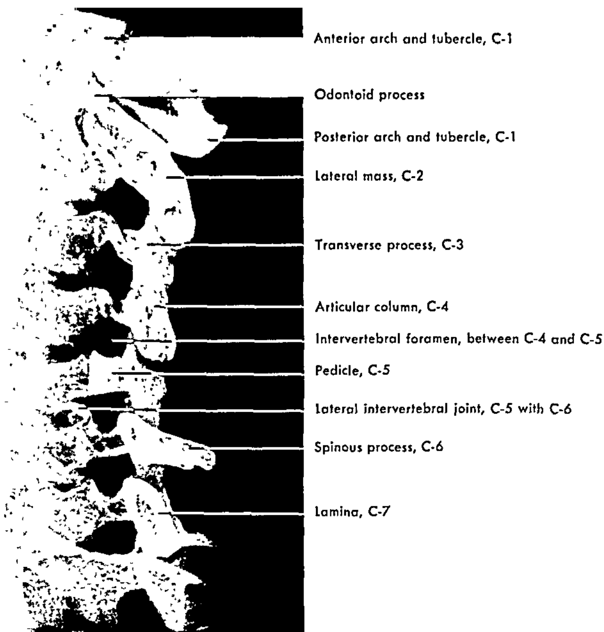
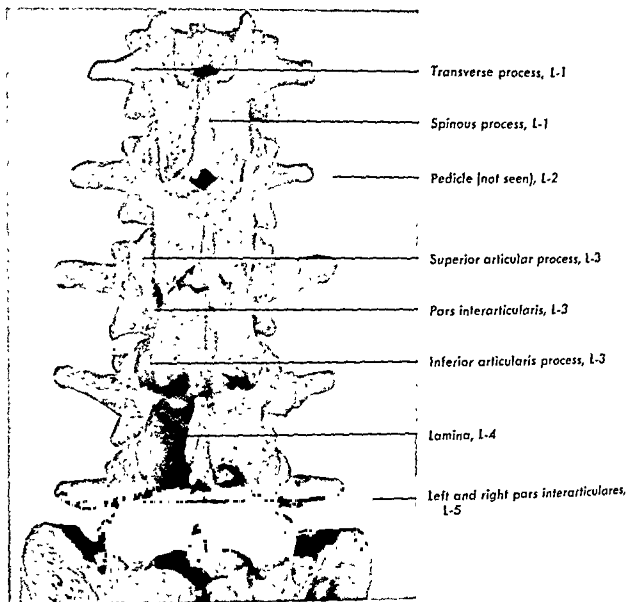

Anterior arch and tubercle, C-1
Odontoid process
Posterior arch and tubercle, C-1
Lateral mass, C-2
Transverse process, C-3
Articular column, C-4
Intervertebral foramen, between C-4 and C-5
Pedicle, C-5
Lateral intervertebral joint, C-5 with C-6
Spinous process, C-6
Lamina, C-7

FIGURE 6



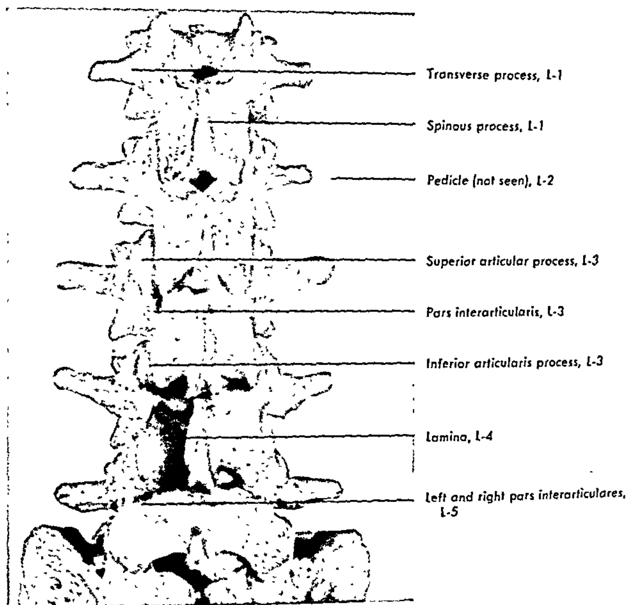
FIGS. 7 and 8. Anteroposterior projection lumbar vertebrae.

changes in the cervical column. The transverse processes appear as relative defects on roentgenograms along a vertical row in the posterior portion of the bodies (Fig. 13).

And, finally, common to both C 1 and C 2 is the absence of distinct pedicles, and between them there is neither an intervertebral disk nor an intervertebral foramen.

The remaining lateral portions can be isolated radiographically into conventional anatomic divisions. These are pedicles; the articular columns with their superior and inferior processes; and the apophysial joints. The pedicles are seen best on the oblique roentgenogram (Fig. 6); the transverse processes, on the anteroposterior projection (Fig. 2); and the articular columns, as well as the apophysial joints, on the lateral view (Fig. 4). The remaining structures completing the cervical vertebra—bodies, lamina, spinous processes—are projected best on the lateral roentgenogram (Fig. 4).

Luschka's joints are situated at the posterolateral borders of the vertebral bodies. The uncus projects upward from the lateral border of the lower body, articulates with the slight concavity of the lateral facet of the inferior border of the upper body and



FIGS. 7 and 8. Anteroposterior projection lumbar vertebrae.

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Transverse process, L-1
Spinous process, L-1
Pedicle, L-2
Superior articular process, L-3
Pars interarticularis, L-3
Inferior articular process, L-3
Lamina, L-4
Pars interarticularis, L-5

FIGURE 8

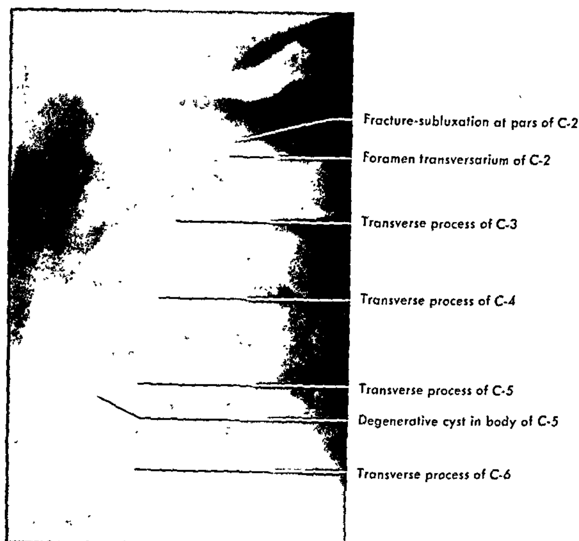


FIG. 13. Fracture through pars of C-2 with subluxation of the body.

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When all the components of each lumbar vertebra are visualized on the oblique roentgenogram, they assume a shape similar to the profile of a "Scottie dog." This is a convenient aid, since parts of the "Scottie dog" conform closely to the vertebral *anatomy in the following manner (Figs.* 11 & 12): (a) nose—transverse process; (b) eye—pedicle; (c) ear—superior articular process, (d) front paw—inferior articular

process; (e) chest—lamina; (f) rear trunk and hind paw—spinous process; (g) neck with collar—pars interarticularis.

SUMMARY

Because of the difficulty in defining normal anatomic components of the vertebral column as they are projected on the roentgenogram, an attempt was made to elucidate these relationships specifically in the cervical and the lumbar vertebrae. Lead paint was found to produce the most satisfactory outlines on roentgenograms. Illustrations of both the painted skeleton and the corresponding roentgenogram are shown in the standard anteroposterior, oblique and lateral positions. The details of the anatomy peculiar to the atlas and the axis are discussed, with special emphasis on the lateral masses and the transverse foramen of the axis. The general architecture of the cervical vertebra is outlined. The lumbar vertebrae are less complex and can easily be broken down by visualizing the side of a Scottie dog on the oblique roentgenogram. A thorough understanding of the vertebral anatomy will lead to detailed interpretation of standard roentgenograms.

Le Structuras Anatomic del Vertebras Cervical e Lumbar e lor Projection in Roentgenogrammas

Summario in Interlingua

A causa del difficultate de definir normal componentes anatomic del columna dorsal como illos es projicite in le roentgenogramma, le effortio esseva interprendite de elucidar iste relationes specificamente in le vertebras cervical e lumbar. Colorante a plumbo se provava le plus satisfactori como medio pro marcar le contornos in le radiogrammas. Illustrationes del marcate skeleto e le correspondente roentgenogrammas es presentate in le positiones standard anteroposterior, oblique e lateral. Le detalios del anatomia peculiar al atlante e al axe es discutite con attention special prestate al massas lateral e al foramine transverse del axe. Le architectura general del vertebra cervical es delineate. Le vertebra lumbar es minus complexe e pote esser particularisate per visualisar in le radiogramma oblique le profilo lateral de un terrier scote. Le precise comprension del anatomia vertebral resulta in le detaliate interpretation de radiogrammas standard.

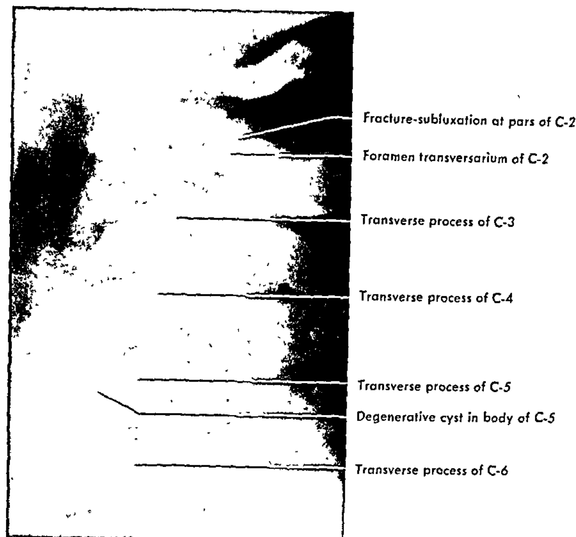


FIG. 13. Fracture through pars of C-2 with subluxation of the body.

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27

Epiphysial Fractures of the Head of the Radius in Children

EARL D. MCBRIDE, M.D.
and
J. CHARLES MONNET, M.D.*

Not infrequently the treatment of fractures in children calls for compromise in the presence of angulation or incomplete reduction. Failure to secure accurate alignment or reduction may arouse skepticism on the part of the parents. A decision to shoulder the responsibility demands full confidence in what regenerative processes will do toward architectural restoration in the growing bones of children. To assure the apprehensive parents that future growth will take care of obvious misalignment is not a simple task. Often the surgeon is pressed into open surgery against his better judgment.

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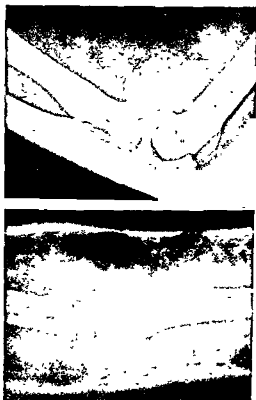


FIG 1. P.H., age 6. Closed reduction; *10-year follow-up*

Fractures about the elbow in children require the utmost caution in treatment. Undue surgical trauma may leave undesirable end-results. The head of the radius in its relation to the capitellum does not carry as much mechanical importance to flexion and extension as do the condyles and the ulna, but it is extremely important in respect to pronation and supination. The usual fracture of the radial head in children is within the osseous-tendinous orbicular ligament. The fracture line may appear to be through the epiphysis, but actually it is a compression of the hard epiphysial head into the soft subepiphysial expansion of the narrow neck that supports the circular disk above; thus, an impaction or greenstick type of fracture is to be dealt with. Complete avulsion of the head may occur, but a true slipped epiphysis is extremely rare.

Generally, it is conceded that removal of the head of the radius in children is inadvisable; however, full confidence in the regeneration of the unreduced epiphysial head is not so well established. Watson-Jones[7] says, "If the head is tilted, forming an angulation for articulation of the capitellum, regenera-

tive powers of growing bone are not equal to correction, and traumatism of the joint will permanently limit extension." Goldenberg[3] states, "When reduction has been incomplete, there is some residual limitation of motion," as demonstrated in one of his cases. Jeffery[4] says, "When manipulative reduction is not then complete in very young children spontaneous correction of deformity may be expected, provided that the angulation does not exceed 20°." Gaston *et al.*[2] state, "With tilt of 20° or more, result is excellent function following successful reduction. Reduction is obligatory in these cases." Blount[1] is more optimistic, in that he says, "With angulation less than 45° the end-result will be surprisingly good. Frequently some limitation of supination, but patients are rarely aware of this. . . . After 3 weeks gross deformity is preferable to open reduction."

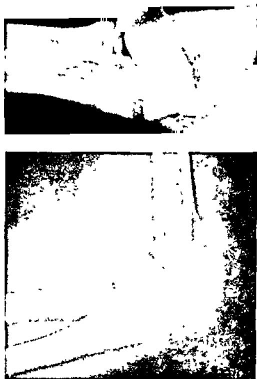


FIG. 2. R.C., age 7. Closed reduction; 5-year follow-up.

A review of the files of the McBride Clinic over a 15-year period revealed the psychological aspect of the surgeon-patient experience in the subepiphysial fractures of the radial head in children. In a number of instances, advice toward conservatism caused the parents to take the child elsewhere for treatment, and no follow-up could be obtained. Other cases had come through dissatisfaction with a previous surgeon who had not attempted reduction or had advised conservative treatment in the face of obvious deformity. The primary object of investigating the results in these patients was to find some who had grown to adulthood and to determine the final extent of architectural restoration. The effort to secure follow-up results in children who had reached maturity met mostly with defeat, because of changes in name and other factors that made it impossible to find the patient or, if he was



FIG 3. P.A.R., age 11. Early open reduction; 10-year follow-up.





FIG. 4. T.C., age 7. No reduction; 15-year follow-up.

found, to get a roentgenogram or a reliable report on the end-result. In the few cases that could be traced it was gratifying to find uniformly normal, or almost normal, restoration in the radial head, even though the last roentgenogram on dismissal from treatment showed considerable angulation. The end-results in open reductions with simple fixation indicated no better results than closed reduction or in those in whom there was no attempt at reduction.

Twenty-nine cases going back to 1943 were reviewed. The age limit selected was 12, and the great majority were under 10 years. Eight of the 29 cases were not included because there was little or no deformity on dismissal at 3 to 5 months after reduction. Only 12 with marked deformity on dismissal (Tables 1 & 2) could be traced who had grown to maturity. The records of 9 of these were early closed or open reduction with no follow-up beyond 12 weeks. In the clinical examination and roentgenograms of the present investigation, these 9 cases of closed reduction that had reached epiphysial closure revealed normal, or almost normal, anatomic restoration and function. In these cases the angulation of the radial head on dismissal had ranged

TABLE 1. NINE CASES OF EARLY CLOSED OR CONSERVATIVE OPEN REDUCTIONS

Case	Age	Injury & 1st Treatment	Degrees Angulation	Treatment and Residual Deformity			Last Roentgenogram	Clin. Result Lim. Mot.
				Closed	Open	Fixation		
PH	6	7/14/48	60° lat.	30°		0	12/10/58 = 10 yrs.	0
RC	7	10/31/53	15° lat. comm.	15°		0	11/30/58 = 5 yrs.	0
PAR	11	12/18/47	35° lat.		0°	0	1/23/59 = 10 yrs.	0
TC	7	9/11/44	30° lat. 30% displaced	Not reduced		0	1/19/59 = 15 yrs.	0
FP	10	10/8/46	70° ant & lat. dislocation, elbow	20°		0	1/31/59 = 13 yrs.	0
DS	10	9/17/52	80° lat & posterior		20°	0	1/20/59 = 7 yrs.	0
CB	9	2/18/52	30° lat.		0°	K wire, head	10/19/59 = 7 yrs.	0
McA	8	7/29/52	35° lat	25°		0	1/10/59 = 6 yrs.	0
DP	11	6/24/55	10° lat.	10°		0	12/6/58 = 3 yrs.	0

TABLE 2. THREE CASES OF LATE OPEN REDUCTION

CASE	AGE	INJURY	DATE OF SURGERY	DEGREES ANGULATION	TYPE OPERATION	LAST ROENTGENOGRAMS	CLIN. RESULTS
	6	5/20/44	6/8/44	30° lat.	Osteotomy	1/18/58 = 14 yrs.	No rotation Radio-ulnar synostosis
DS	9	11/15/43	12/21/43	15° lat. 70% displacement. Dislocation elbow	Osteotomy Chromic suture	6/14/53 = 10 yrs.	No rotation Flexion to 50° Extension = 170° Radial head later excised
SAN	12	9/25/54	9/15/55	60° lat.	Osteotomy K wire, Head	1/17/59 = 5 yrs.	Extension = 160° Flexion = 85° Rotation = 40°

from 10° to 80°. Three had open reduction with simple fixation: in 2 of these a Kirschner wire was placed through the center of the epiphysial head, and the third had fixation with chromic suture only.

THREE CASES OF LATE OPEN REDUCTION WITH POOR RESULTS

Three of the 12 cases resulted in deformity and partial ankylosis. These represent the resulting casualty to the head of the radius that may happen from late open reduction or osteotomy in a growing child (See Table 2.) Our experience coincides with that of others who have written previously on the subject of epiphysial fractures of the radial head in children; they emphasized the advisability of closed reduction and cautioned against late open reduction requiring undue surgical trauma

Case I. Age 12 years. Injury sustained on September 25, 1954. The patient was treated elsewhere by plaster cast for 5 weeks On admission to the hospital there was 45° outward angulation and 30 per cent lateral displacement. Extension was 135°, flexion, 45°. Pronation was limited to 5° and supination to 30° Open reduction was done on January 15, 1955 Osteotomy and leverage were necessary. Fixation was Kirschner wire through center of the radial head. Roentgenogram taken on July 10, 1955, showed that some angulation still was present. Also, there was redundant bone growth about the head and the neck.

The final result on January 17, 1959, at 17 years of age, was severe deformity of radial head; extension, 160°; flexion, 85°; loss of rotation, 40°.

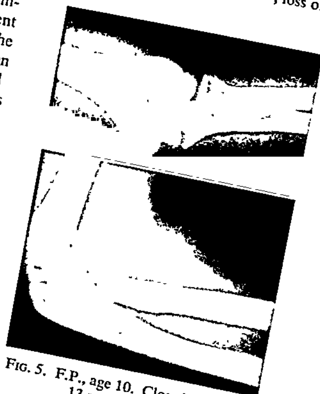


FIG. 5. F.P., age 10. Closed reduction; 13-year follow-up.



Fig. 6. D.S., age 10. Closed reduction; 7-year follow-up.

Case 2. Age 6 years. Injury sustained May 20, 1944. The patient was treated elsewhere until admission to the hospital on June 8, 1944. Lateral angulation was 30°; flexion, 50°; extension, *160°*. *Open reduction, osteotomy*, was carried out on June 13, 1944.

Final examination on January 18, 1958, at 21 years of age, revealed no rotation because of radio-ulnar synostosis; extension, 180°; flexion, 40°

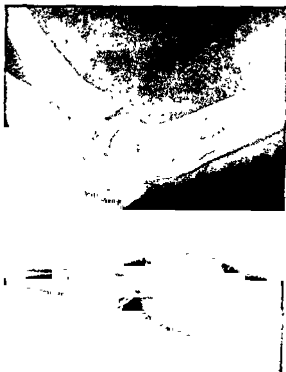


Fig. 7. C.B, age 9. *Open reduction*; 7-year follow-up.

Case 3. Age 9. Injury sustained on November 15, 1943. The patient was treated elsewhere until admission to the hospital on December 21, 1943. There had been a dislocation of the elbow with *fracture of the head of the radius. Also, there* was fracture of the lower end of the radius near the lower epiphysis. Deformity of the head of the radius was 70 per cent displacement with 15° lateral angulation. Open reduction, osteotomy, was performed on December 21, 1943. The radius was reduced with good alignment and fixed with chromic suture. Considerable deformity and limited motion existed until June 15, 1945, when the head of the radius was excised.

Final examination on June 23, 1953, disclosed that there was no rotation but that extension was limited to 170° and flexion to 50°.

Closed reduction under general anesthesia should be attempted in most cases. Preceding the anesthetic the parents should be fully informed of the peculiarities contingent upon the treatment of this fracture. The manipulations of closed reduction have been well described by Blount,[1] Jeffery,[4] Patterson,[6] Goldenberg,[3] Watson-Jones[7] and others. However, often the fracture is of the greenstick type, or it is impacted to the extent that no amount of direct pressure or manipulative maneuver is effective enough fully to correct the angulation. Usually the head of the radius is displaced forward and outward. Full extension and supination will present the opportunity to press the thumb against the radi while the forearm is forced inwar counter force applied to the

medial condyle. When it is proved by roentgenogram that as much reduction as possible has been accomplished, the elbow is flexed at a right angle with the forearm in full supination and fixed by anterior and posterior plaster splints. Passive motion is begun at 3 weeks, and the splints are removed at 4 weeks.

Open reduction of this particular fracture is fraught with possibility of further epiphysial damage. No matter how gentle the surgeon tries to be, usually there is more surgical trauma than expected, and this is especially true if internal fixation is attempted. By opening the orbicular capsule in fresh fractures, the tilted fragment may be pressed over into alignment, but, if it is rotated and firmly impacted, it will require considerable leverage and then not stay in place. At this point there is the temptation to do too much. Usually, tight closure of the orbicular ligament is all that is necessary for fixation. One of the simplest measures of fixation is to extend a small-size Kirschner wire through the center of the head into the neck, leaving enough wire extended through the skin to remove it within 10 days. No attempt should be made to drill holes or to reshape the fragments.

When open reduction to the radial head is attempted in the presence of other damage to the elbow, the end-result is likely to be poor. Open reduction 2 or 3 weeks after injury is certain to cause undesirable deformity of the radial head. Operative damage to the adjacent ulna may result in radioulnar synostosis or at least in severe limitation of pronation and supination. It is agreed with Blount and others that in such cases it is preferable to leave the deformity alone and to remove the radial head after maturity if it is blocking motion. The probability is that this will not be necessary.





FIG. 8. McA., age 9. Closed reduction; 6-year follow-up.



FIG 9. D.P., age 11. Closed reduction; 3-year follow-up.



Fig. 10. J P., age 10 Late osteotomy reduction; 14-year follow-up with synostosis of radius and ulna.

CONCLUSION

The end-results at epiphysial maturity are presented on 12 cases out of a total of 29 fractures of the head of the radius in children under 12 years of age. The 9 cases of closed reduction or cautious open reduction *indicate that when angulation is not fully* corrected, the surgeon can very well depend on the regenerative processes of the epiphysial radial head in children under 12 to restore normal, or almost normal, architectural design *by the time that maturity is* reached.

More extensive surgery of open reduction as required in late reduction or osteotomy, and when there is involvement of other portions of the elbow, is likely to result in severe permanent deformity of the radial head and regrettable ankylosis.

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Fig. 11. D.S., age 9. Late osteotomy reduction; 10-year follow-up with synostosis of radius and ulna.





FIG. 12. S.A.N., age 12. Late osteotomy reduction; 5-year follow-up with radial head deformity and severe limitation of rotation.

Fracturas Epiphysee del Capite del Radio in Patientes Pediatric

Summario in Interlingua

Le resultatos final al tempore del completion del maturation epiphysee es presentate in dece-duo casos ex un serie de vinti-novem fracturas del capite del radio in patientes de minus que dece-duo annos de etate. Le novem casos de reduction claudite o de caute reduction aperte indica que quando le angulation non es completemente corrigite, le chirurgo pote fider se del processos regenerative in le capite epiphyseo-radial de juvenes de minus que dece-due annos de etate con respecto al objectivo de restaurar un normal o quasi normal architectura al tempore quando le patiente attinge su maturitate.

Casos de plus extense chirurgia in reduction aperte, requirite per exemplo sub le conditiones de un reduction retardate o de osteotomia, e casos in que altere portiones del cubito es afficite, resulta con alte grado de probabilitate in sever deformitate permanente del capite radial e in un forma regrettabile de ankylosis.

28

Local Ischemic Necrosis of the Leg*

IVAR J. LARSEN, M.D.,† EDWARD W. BOONE, M.D.,†
ELLIOT L. COLES, M.D.,‡ and W. HAROLD CIVIN, M.D.†

In 1872 Volkmann described a case of ischemic necrosis of the leg following application of a splint with a circular bandage. During the next 75 years ischemic necrosis of muscle has been a popular subject, but interest orthopaedically has been centered in the lesion in the forearm associated with Volkmann's name. During World War II, attention became focused on the anterior crural compartment with reports of the development of ischemic necrosis from extended marching and without trauma. The importance of the closed compartment and terminal arterial blood supply to this part of the leg has been stressed. However, the frequency of occurrence of ischemic necrosis as a complication of everyday orthopaedic procedures has not been conspicuous in orthopaedic literature, and it is to emphasize further the danger zone of the proximal tibial area that the following three cases are being reported.

Case 1. J. K., a 55-year-old Hawaiian male, was injured on February 20, 1957, when he fell a distance of about 4 feet and landed on his extended left leg. He sustained a compression fracture of the lateral table of the left tibia with moderate depression. He had no other significant injuries from the fall.

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PAST HISTORY. In 1943, urinalysis at the time of hemorrhoidectomy showed a trace of albumin and RBC 60 to 70 per HPF. His blood pressure was 120/80. There was no other contributory history.

HOSPITAL COURSE. On admission to the hospital, the patient showed moderate ecchymotic swelling around the left knee and the proximal lateral tibial area. The dorsalis pedis and the posterior tibial pulsations were present; no neurologic deficit was noted. General examination was noncontributory. His blood pressure on admission was 145/90. Urine on admission showed albumin 2+, RBC 8 to 10 per HPF, and occasional hyaline and granular casts. The knee was ice capped for 24 hours, and, on February 21, 1957, about 18 hours after the injury, under spinal anesthesia, after removing 90 cc. of blood from his knee, a manipulative reduction was done by forcefully adducting the tibia with lateral countertraction on the medial femoral condyle by a cloth sling. A favorable reduction was accomplished, and a long leg cast was applied with the traction forces held during application of the cast. With spinal anesthesia, the patient's blood pressure fell to 90/60 and fluctuated between 90 and 100/45 and 90 for the next 4 hours. Seven hours after operation the pressure was 170/110 and varied from 160 to 180/90 to 100 for the next 48 hours, thereafter remaining around 140/90 until discharge.

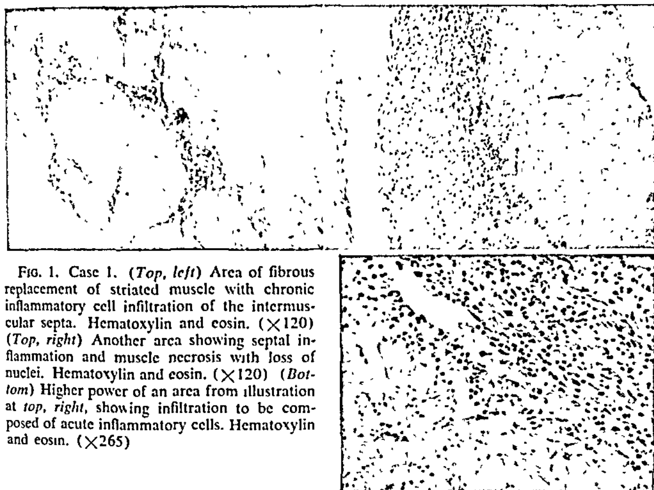


FIG. 1. Case 1. (*Top, left*) Area of fibrous replacement of striated muscle with chronic inflammatory cell infiltration of the intermuscular septa. Hematoxylin and eosin. (×120) (*Top, right*) Another area showing septal inflammation and muscle necrosis with loss of nuclei. Hematoxylin and eosin. (×120) (*Bottom*) Higher power of an area from illustration at *top, right*, showing infiltration to be composed of acute inflammatory cells. Hematoxylin and eosin. (×265)

Postoperatively the patient complained of the usual amount of discomfort around the knee. Toe circulation remained good, and no numbness was complained of. The long leg cast obscured detailed sensory examination or palpation of the arterial pulses, but capillary pulse remained good, and no undue swelling developed.

On the third postoperative day, the patient had slight chills and developed a spiking temperature ranging from 99.6° to 102.2° for the next few days. Concurrent with this fever his hematuria became gross with an albumin of 4+ and numerous casts. This cleared gradually on a medical regimen, and, on March 7, his fourteenth postoperative day, his urine was clear, his blood pressure was 140/80, and his temperature was normal and remained so until his discharge —ambulatory on crutches on the sixteenth postoperative day without significant leg pain.

On April 5, 7 weeks after the injury, the cast was removed, and a long leg brace was applied. It was noted at this time that there was a complete peroneal nerve palsy. Generally, the leg was firm and indurated over the anterior tibial compartment, and no atrophy of the muscles could be appreciated. The circulation to the foot appeared to be adequate, but dorsalis pedis and posterior tibial artery pulsations were not recorded specifically.

He was started on physical therapy with electrical stimulation to the muscles, and during the next 6 weeks he showed fairly good return of the superficial nerve sensation but no significant motor return. (Neurosurgical consultant advised continued physical therapy) However, without further functional or sensory return, on July 16 (5 months after the injury) an exploration of the peroneal nerve and muscles of the anterior compartment was done. The muscles were found to be grossly degenerated with considerable fibrous and fatty infiltrations into



FIG. 2. Case 2. (*Left*) Bundles of necrotic, partly hyalinized muscle with loss of nuclei. Hematoxylin and eosin. (×120) (*Right*) Higher power of anuclear necrotic muscle bundles. Hematoxylin and eosin. (×265)

the necrotic muscle mass (Fig. 1). The extensor hallucis and the tibialis anticus were the most severely involved, the peroneals and the toe extensors slightly less. The nerve appeared to be normal except for focal areas, where fibrotic constriction was evident. There was minimal nerve response in the proximal portion of the muscles to galvanic stimulation. Sections of muscle were taken for microscopic examination. These showed the typical changes of ischemic necrosis of muscle. (See Fig. 1.) In spite of the neurolysis, there was no further clinical evidence of muscle return; consequently, on February 21, 1958, 1 year after the injury, a posterior tibial transplant through the interosseous membrane to the dorsum of the foot was done, and at the same time the muscles were re-explored and sections taken (See Fig. 1.) No evidence of regeneration was noted.

Case 2. T. M., a 35-year-old Japanese painter. This man was admitted to the hospital following a fall from the roof of a quonset hut in which he sustained a comminuted, displaced fracture of the left os calcis

PAST HISTORY This was completely noncontributory, as was his systemic review, his health having been excellent except for the usual childhood diseases and meningitis.

HOSPITAL COURSE. The foot was elevated, compressed and ice packed for 48 hours, and on the third hospital day he was taken to surgery, where, under spinal anesthesia, two Steinmann pins were inserted into the distal portion of the tibial crest and a third pin into the os calcis. A reduction of the os calcis was performed by manipulative technic with strong traction applied to the pins. A cast was applied with the traction maintained, the pins being incorporated within the cast.

Within 4 hours after spinal anesthesia the patient had complete sensory return as well as movement of the toes, and, aside from the usual amount of pain, the circulation and the general appearance of the foot were satisfactory. Twenty-four hours after surgery, the patient complained of sharp pain in the left leg, indicating the pretibial area as the source, and also of "needles in the toes of the left foot." The toes were warm, the motion was good, and capillary pulsations were quite satisfactory, but the cast prevented palpation of the dorsalis pedis and the posterior tibial vessels. The sensations of pain and paresthesia in the leg con-

tinued. On the third day, the patient described the pain as "intolerable" in the left pretibial area, but the distal circulation appeared to be quite adequate. In view of the absence of any further objective evidence of impairment of circulation, the leg was not inspected, and the pain was controlled by morphiates.

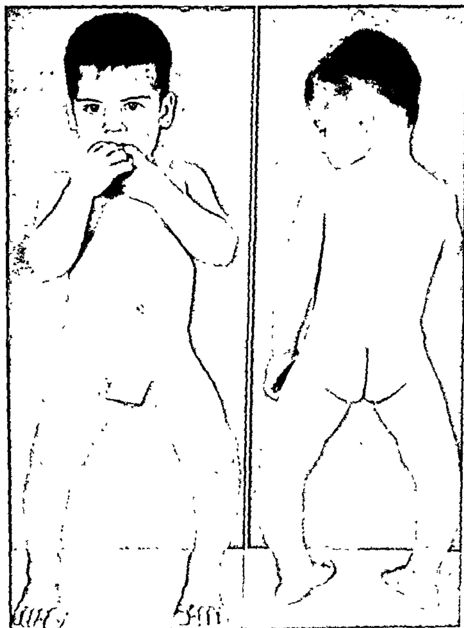
Urinalysis and blood count on the patient's admission to the hospital were within normal limits, and, unfortunately, no subsequent urinalysis was done during his hospital stay, in spite of the fact that he developed a low grade fever starting on the afternoon of the first postoperative day, and for the next 4 days his temperature fluctuated between 99.4° and 100.8° orally. He was afebrile thereafter. His pain subsided, gradually, and he became ambulatory on crutches. There did not appear to be any untoward reaction in the leg or the foot at the time of discharge on March 25, 1957, 10 days after admission to hospital.

He was seen again as an outpatient on April 5, 21 days after the injury, at which time he was complaining of fever and chills, and his urinalysis at that time showed an albumin of 1+ with a moderate number of both red and white cells and a few scattered hyaline casts. He was given erythromycin by mouth and returned 3 days later free of complaints of fever and chills. The urine had cleared, and he had no further complaints.

He was seen again on April 22, about a month after his closed reduction, and at that time the pins were removed through a window in the cast. Six weeks after operation, the cast was removed, and there was found to be a large draining area at the site of the distal tibial pin. The muscles of the anterior compartment could be seen through this hole in the skin, and it was evident that there was extensive necrosis of the anterior tibial muscle. For the next 2½ months the patient presented himself regularly for dressings, and on each occasion more necrotic muscle sloughed from the pin site He was treated with local and systemic antibiotics, in spite of which the drainage failed to subside. Almost 4 months from the onset—on July 8—he was returned to surgery, at which time radical débridement and open packing of the wound were done under spinal anesthesia. Following this the wound healed fairly rapidly. The microscopic description of the muscles showed extensive necrosis and fibrosis compatible with an old ischemic necrosis (Fig. 2). The patient developed a rather firm contracture of the muscle bellies of the dorsiflexors. His peroneals were not involved appreciably, the major involvement being in the extensor hallucis and the tibialis anticus. With fibrotic contracture of the muscles, a satisfactory tenodesis was established, so that the patient did not have any significant amount of drop foot and was able to get along fairly well without any active muscle power but with a passive check to plantar flexion.

Case 3. A 2-year-old child was admitted to the hospital because of severe genu varum with internal rotation of the tibia (Figs. 3 & 4). On May 2, 1957, bilateral tibial osteotomies were done in the proximal thirds with removal of a portion of each fibula. Correction of the bowing and rotation was effected, fixation was maintained with Steinmann pins in the proximal and the distal fragments, the pins being incorporated in the plaster (Fig. 5). Postoperatively the patient ran considerable temperature elevation, starting on the first postoperative day. In addition, he showed generalized toxicity, as well as albuminuria with multiple red and white cells and granular casts in the urine. He was put on antibiotics, and the temperature subsided gradually over a period of about 7 to 10 days. The distal circulation to the toes at all times appeared to be good, and the patient was not unduly irritable. The casts were not changed and the wounds were not inspected until 3 weeks postoperatively. At this time there was found to be an extensive area of necrosis of the skin,

subcutaneous tissues, aponeurosis and muscles over the anterior compartment of the leg, extending down to the interosseous membrane and exposing the tibia and the fibula (Fig. 6). On June 6, 35 days postoperatively, débridement of necrotic skin and muscle was done. Clinically, at this time the muscles of the anterior compartment appeared to be in various stages of necrosis and fibrosis, with colors from green and yellow to pale white. No normal muscle was evident (Fig. 7). A third débridement was done a week later, and on June 20 a split-skin graft was applied to the open wound after several days of preparation with wet dressings. There was about 50 per cent take of the skin graft. Satisfactory healing of the wound finally occurred (Fig. 8), and the patient was allowed to return to his home, on another island, 159 days after his original operation. However, the drainage soon returned to the lower part of the wound (Fig. 9), and he was readmitted to hospital on December 30, 1957, at which time further débridement and removal of infected portions of the fibula were done. Following this, the wound healed gradually, and it has remained closed to date. The osteotomies



Figs. 3 to 9, Case 3.
Fig. 3. Preoperative photographs.



FIG. 4. Preoperative roentgenograms, April 19, 1957.



FIG. 5. Postoperative roentgenograms showing bilateral osteotomies and fixation pins incorporated in cast.

healed nicely in spite of the vascular complications, and apparently there was no nerve involvement present. (Figs. 3-8)

The patient developed cicatricial scarring of the musculotendinous portions of the mucles, so that little drop foot was present, the scarred fibrotic muscle bellies acting as good check reins to a drop foot.

DISCUSSION

The above three cases have little in common other than trauma to the proximal tibial area. A different, frequently encountered orthopaedic procedure was the precipitating cause in each case. The age of the patients covered the span of 2 to 55 years. No common systemic disease was evident as a predisposing cause.

Ischemic or Volkmann's necrosis has been reported frequently in fractures of the femur and the proximal tibial areas, and has been reproduced experimentally by interruption of the popliteal or the anterior tibial arteries in rabbits. Undoubtedly, complications arise much more frequently than is recognized, as would be indicated by analyses of cases by Thomson,[30] in which 18 of 42 cases were in the lower extremities. (Thomson also reported one case following a rotation osteotomy but gave no details of the procedure.) Albert and Mitchell,[1] in discussing Volkmann's ischemic contracture of the leg, described three cases following fracture of the femur with calcification in the muscles of the anterior compartment. They reviewed the experiments of Brooks[4,19] and felt that the ischemic necrosis was a result of interference with the arterial blood supply. Indications that many cases are missed also is implied by Ellis[13] in his analysis of end-results of fractures of the tibial shaft. He points out that 6 per cent of tibial shaft

fractures had restricted ankle motion and that a third of these were a result of partial or focal ischemic necrosis through the muscles of the leg. That ischemic necrosis of muscles of the anterior compartment can develop without any trauma has been emphasized by numerous writers.[20,21,24,27,29] It is felt that the necrosis is probably a combination of several factors. Anatomic configuration of this compartment is such that it is closed except for the distal portion where the tendons exit. The anterior tibial artery is vulnerable, as it enters through a very small and fixed aperture at the top of the interosseous membrane. Blood supply to the muscles of the anterior compartment has been worked out in detail, and it is quite evident that, to a certain extent, the supply is from "terminal" vessels.[2,6,24]

The anterior tibial muscle is supplied almost entirely by the anterior tibial artery through a series of segmental branches approximately 12 in number, which divide into ascending and descending divisions, anastomosing by a system of arcades. The proximal third of the muscle is supplied by a leash from the anterior tibial recurrent artery. Intramuscular anastomoses are so fine that their functional significance is open to doubt. . . .

Extensor hallucis has a twofold supply: (1) from the anterior tibial artery and (2) from the



FIG. 6. Three weeks after operation, after débridement of necrotic tissue

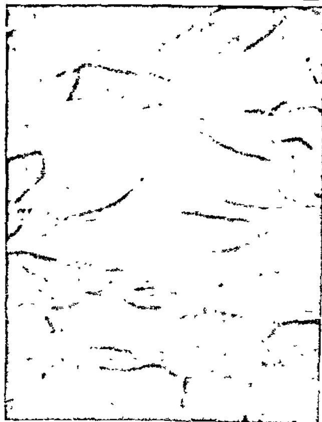


FIG. 7. (*Top, left*) Area of necrotic anuclear muscle with infiltration of degenerated muscle and intermuscular septum with acute inflammatory cells. Hematoxylin and eosin. (×120) (*Top, right*) Another area showing degenerating muscle with little inflammatory reaction but with marked shrinking of sarcoplasm from the sarcolemmal borders Hematoxylin and easin. (×120). (*Bottom*) Higher power of area from illustration at *top, right*. Loss of nuclei and disappearance of cross-striation are also seen.

perforating peroneal artery. The intramuscular anastomosis is described as rectangular and much less efficient than that of other muscles. The extensor longus has a threefold supply: (1) that coming from the anterior tibial and its recurrent branch; (2) 3 large perforating branches from the posterior tibial; (3) large perforating branch in the lower third of the

muscle from its perforating peroneal artery. There are anastomoses throughout the length of the common extensor longus muscle

This may account to some extent for the fact that the involvement is much more frequent and complete in the tibialis anterior, less so in the extensor hallucis, and even less frequently in the extensor longus. With trauma to the proximal portion of the anterior compartment, whether the vessel actually is damaged or not, the increased pressure within the tight compartment, together with a certain amount of arterial spasm, is obviously sufficient to cause at least segmental spasm of the vessels and, if maintained for a long enough period of time, ischemic necrosis. In our case of the osteotomy, the fascia of the anterior compartment was not closed, and it would appear that the injury was a direct one to the vessel itself. In this case the pins were inserted parallel to each other and through the cortices of the tibia, the osteotomy was done between the pins and rotation was carried out with the pins in place. It is quite conceivable that a torsional effect directly on the vessel could have been the cause. The procedure was performed under a tourniquet, and, of course, any local ischemia at the time of surgery was obscured. Diagnosis may be difficult when a long leg cast obscures local findings. As the necrosis is a limited one, the circulation to the exposed portion of the foot is not impaired significantly. More careful attention to the

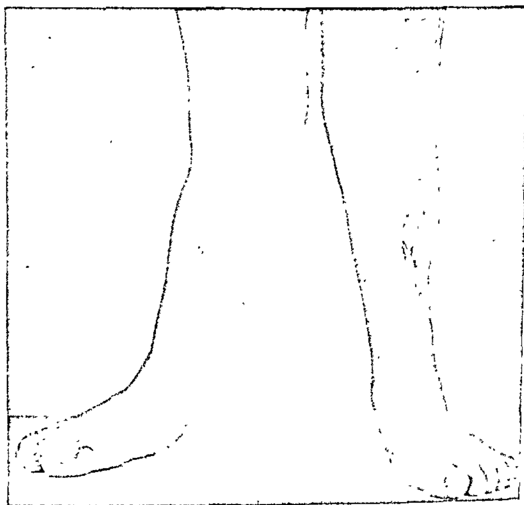


Fig. 8. Almost 5 months after operation.

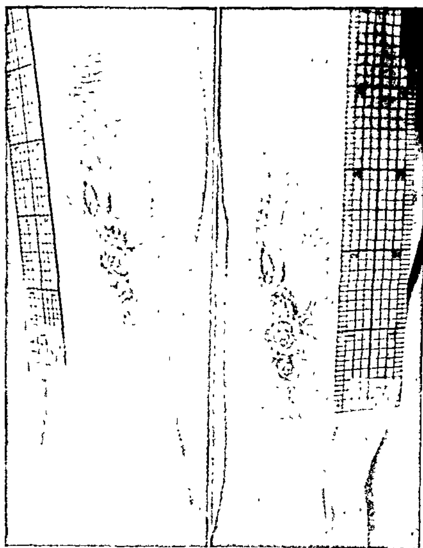


FIG. 9. Almost 8 months after operation. Recurrent drainage with osteomyelitis of the fibula.

symptomatology of acute pain in the anterior tibial region or paresthesias or numbness, or to evidence of systemic response of varying degrees manifested by fever, leukocytosis or urinary changes indicating lower nephron nephrosis, should be watched for as an aid to recognizing the condition early. It has been shown that frequently spinal anesthesia will relieve the arterial spasm and also decompression of the anterior chamber by incising the fascia if indicated if diagnosis can be made early. In Cases 1 and 2, had the condition been recognized in its early stages, decompression of the compartment by fascial splitting could have minimized the disability to a great extent. When necrosis has not been too extensive, there are indications that muscle regeneration can take place[7-10,24] and considerable function returned.

CONCLUSIONS

1. Ischemic necrosis of the muscles of the anterior crural compartment is a fairly frequent complication of trauma to the proximal tibial area.

2 Three cases developing after routine orthopaedic procedures are reported.

3. The proximal third of the tibia should be regarded as a danger zone for vascular damage, even with minimal or no trauma.

4. Systemic symptoms of fever, leukocytosis and, sometimes, evidence of kidney damage (lower nephron nephrosis) may be the only clinical indications of the syndrome, especially in children, and/or when the leg is enclosed in a cast.

5. Early decompression of the anterior compartment or direct attack on the artery may be indicated for favorable recovery.

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Local Necrose Ischemic del Gamba

Summario in Interlingua

Le autores presenta tres casos de necrose ischemic del gamba que se disveloppava post commun manovras orthopedic. Le condition es melio cognoscite sub le designation de contractura ischemic de Volkmann, specialmente quando il se tracta del bracio. In le

presente casos illo concerneva le compartimentos anterolateral del gamba, incluse le sequente musculos: anterotibial, extensor de hallucc longe, extensor digital commun, e peronee longe e breve.

In le tres casos le condition resultava de communmente empleate mesuras orthopedic; i.e., fixation del tibia per clavo de Steinmann, osteotomia rotational del tibia in patientes pediatric, e fractura del plateau tibial. Le etates reportate es ab duo a cinquanta-cinque annos. Es signalate le frequentia del condition e le difficultate de diagnosticar necrose local in patientes immobilisate in un apparato de gypso. Es notate le frequentia de reportos in le litteratura de casos sin trauma specific. Es mentionate le correlation del constatationes local con manifestationes systemic e indicationes de varie grados de nephrose inferonephronic.

SECTION III

ITEMS

29

Multiple Joint Lesions in a Young Negro Adult Exhibiting the Sickle-Cell Trait

DONALD YEOMAN STEWART, M.D.*

The occurrence of osseous lesions in patients exhibiting sickle cell anemia, with or without crisis, has been well recognized in orthopaedic literature. The possibility that similar types of bone lesions or that heretofore undocumented bone lesions might occur in the sickle cell trait has received much less recognition. The simultaneous occurrence of bilateral subtalar arthritis, osteochrondritis dissecans of the knee, the hip, and the shoulder, and Marie-Strümpell-like sacro-iliac lesions in a patient with the sickle cell trait has stimulated this report.

Case Report. A 25-year-old single Negro male veteran first experienced the onset of symptoms at the age of 19, when he awoke one morning with a painful swelling of the right knee unassociated with increased heat or redness. His family history was unremarkable except for the fact that his grandmother had complained of multiple nondeforming myalgia and arthralgia. In the next 4 months he noted similar episodes of migratory arthralgia in the left knee, the right ankle, the right elbow and the left shoulder. During this time he lost 30 pounds.

He was hospitalized at the Portsmouth Naval Hospital, where a diagnosis of rheumatoid arthritis was made. He received intramuscular chrysotherapy, salicylates, physiotherapy and thiamine for about 9 months, with mild improvement.

Four years prior to the onset of his symptoms he had been treated with penicillin for *gonococcal urethritis*.

About 2 years after the onset of his disease he was hospitalized at the Dearborn Veterans Administration Hospital because of 6 months of persistent pain and swelling of the right knee, pain in the left shoulder, pain in both heels and pain in the right ankle. Physical examination at that time revealed marked swelling and tenderness of the right ankle and knee. Laboratory studies revealed a normal complete blood count, serology, urine, febrile agglutinations, electrocardiogram and chest roentgenogram. Roentgenogram of the right knee at that time disclosed a moderate-sized defect of the medial femoral condyle and articular portion of the patella. He was treated with further physiotherapy and chrysotherapy, with moderate improvement.

He was admitted to the Ann Arbor Veterans Hospital on November 2, 1956, complaining of an exacerbation of pain in the left shoulder due to an automobile accident, "rattling" in his right knee of 5 years' duration, pain and swelling in the right foot and ankle, and bilateral heel pain of 5 years' duration. He denied back pain, gluteal pain or sciatic radiation.

PHYSICAL EXAMINATION. Blood pressure, 130/80 both arms Temperature, 98.6. Pulse, 80. Respirations, 16. A tall asthenic, lethargic, passive colored male who did not seem in any acute distress and was able to walk with very little limp and with a fairly normal gait. There were no obvious abnormalities. No pallor, icterus or cyanosis. The cardiovascular system was negative except for what was interpreted as

* Written while the author was a resident in orthopaedic surgery on the service of Dr. Carl Badgely, at the University Hospital of Ann Arbor, Mich ; finished when he was senior resident in orthopaedic surgery at the Akron General Hospital, Akron, Ohio.



FIG. 1. Osteochondritis dissecans type defect in femoral condyle, found in a 25-year-old Negro male, who complained of recurrent pain, "rattling" and effusion of the knees. Electrophoretic pattern revealed classic "S-A" hemoglobin pattern.

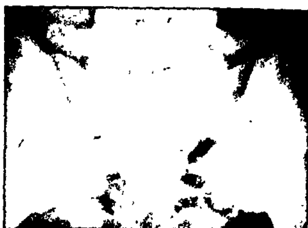


FIG. 2. Bilateral sacro-iliac sclerotic changes suggestive of Marie-Strümpell-like lesions found in a 25-year-old Negro male with the proven sickle-cell trait but without any back pain.

a functional murmur. Chest expansion was normal. Slight pain and crepitus were present over the left greater tuberosity of the humerus. Severe patellofemoral crepitus, without any limitation of motion, redness or increased heat, was present in both knees, unassociated with any quadriceps atrophy. None of the muscles exhibited any significant atrophy. The right subtalar joints revealed tenderness, slight periarticular induration, pain on motion, with some limitation of motion. His fingers were long and thin, he was mildly hyperelastic, and his feet were splayed, with slight pes planus. The spine revealed normal dynamics and contours, and was without pain or tenderness.

LABORATORY STUDIES. Normal hemoglobin, hematocrit, platelet, white blood count, urine, blood urinary nitrogen, blood sugars, blood calcium and phosphorus, alkaline phosphatase, 24-hour urinary urobilinogen, blood van den Bergh, thymol turbidity and heterophil agglutination. The antistreptolysin titre, uric acid, C-reactive protein, sedimentation rates and sheep cell agglutination tests for rheumatoid arthritis were negative. Sickling preparation revealed 95 per cent sickling in 24 hours, 80 per cent in 12 hours and 1 per cent in 2 hours. The hemoglobin paper electrophoretic pattern revealed that about 20 per cent of the hemoglobin was that of the sickle cell trait, and about 80 per cent was normal The erythrocyte fragility test showed increased resistance to hypotonic saline. The serum proteins were 8.2 Gm., globulins 5.2 Gm

ROENTGENOGRAMS. Bilateral sclerosis, slight cystic change and some loss of the joint space were present in the sacro-iliac joints (Fig. 2). Narrowing of the joint space, sclerosis and hypertrophic spurring out of proportion to the patient's age were present in the right subtalar joints (Fig. 3). Hypertrophic spurring and bilateral erosive defects in the femoral condyles and intercondylar notches were present in both knees (Fig. 1). Both hips showed very early cortical irregularity and sclerotic changes near the ligamentum teres insertion Both humeral heads revealed irregular erosive defects over the greater tuberosities (Fig. 4). Areas of periosteal elevation were present in the distal tibias and fibulas.

DISCUSSION

The diagnosis of rheumatoid arthritis was questioned because of the lack of any constitutional deterioration or toxicity, the lack of any hand changes, the marked paucity of muscular atrophy, contractures or ankylosis, the benign nature of the subjective complaints and disability, and the negative battery of chemical and serologic tests that usually are accepted as positive in a large preponderance of patients with rheumatoid arthritis. The diagnosis of sickle cell trait arthritis was invoked (1) because of the well-documented proof of the existence of

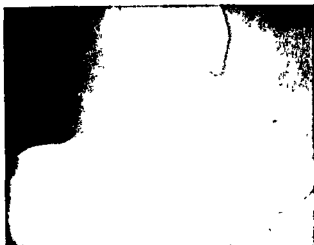


Fig. 3. Unilateral subtalar hypertrophic arthritic change in a 25-year-old colored male who exhibited the sickle-cell trait and complained of recurrent pain and chronic effusion of the ankle.

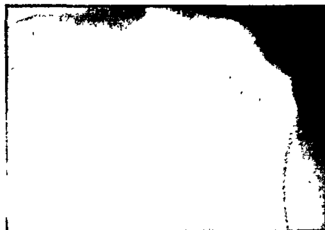


Fig. 4. Irregular humeral tuberosity defect in a 25-year-old Negro male without any history of dislocation of the shoulder. Exhibited proven sickle-cell trait. Rare episodes of pain and limitation in the shoulder.

the sickle cell trait in this case by microscopic fragility studies and paper electrophoretic study; (2) because of the absence of many features of rheumatoid arthritis (or of any form of arthritis) that ordinarily are considered to be essential to subtantiate the diagnosis; (3) because of the fact that similar osseous changes have been reported in conjunction with the trait by other clinicians;[3,8,10,39,38,56] (4) because at last there is now available histologic,[20,63,1,31,34 29 15,17,3,38] biochemical,[56,42,43] and genetic[62,26,27,40] truths that furnish the basis on which to formulate a hypothesis explaining this case in a plausible way.

It has been the fusion of the newer genetic discoveries with the modern biochemical and physiologic concepts of sicklemia that has given clinicians the unified concept that was needed. The fact that the nature and the location of the osseous changes do not correlate with either the severity of the crises or the anemia creates a need for another hypothesis in addition to that of intramedullary hematopoiesis.

In spite of the recognition of the genetic basis for sickling and its inheritance according to mendelian law,[15,62] clinicians have been slow to place the fundamental defect in the intrinsic nature of the hemoglobin within the erythrocyte rather than in the mere shape of the erythrocyte or the presence or the absence of crisis or anemia.[8,53,45] By means of hemoglobin electrophoresis we are now able to differentiate a number of previously unidentified forms of hemoglobin that behave as simple mendelian dominants and are allelomorphic with normal and sickle cell hemoglobin.[58,26,27,52,23] The clinical manifestations of patients with these forms of hemoglobin have been found to correlate well with the percentage of sickle cell hemoglobin in the erythrocytes. Thus, patients with the fully developed picture of sickle cell anemia show electrophoretically 80 to 100 per cent abnormal hemoglobin, while those with the trait would possess only 25 per cent abnormal hemoglobin.[68] Every case found to have a genetic variant of sickle cell anemia has been discovered on clinical examination alone, atypical for sickle cell anemia.[55] Therefore, the concept has evolved that sickle cell disease actually includes any disorder in which manifestations of the disease are attributable to the presence of "S" type hemoglobin, whether it is homozygous (sickle cell anemia) or heterozygous (sickle cell trait).

The pathologic precipitation of sickle cells is not associated with any change in the life expectancy of the cell but with accumulation of a critical number of aging cells. There is always a progressive rise in the number of circulating sickle cells prior to an episode of vascular blockade. The erythrocytes of the patient with sicklemia exhibit an increased tendency to sickle as they mature. Since the sickle cell hemoglobin does not affect the longevity of the erythrocyte, abnormal forms increase progressively during quiescent periods until mechanical obstruction occurs.

The vascular blockade in bone probably ensues in the following manner:

The maximum distortion of the sicklemic erythrocyte occurs in the bone marrow because anoxemia is greatest at this point, and anoxemia enhances greatly any sickling tendency.[52] The sickle cells become birefringent when viewed through a polarizing microscope, and this is associated with an increased fragility to mechanical trauma.[39] This fragility, when combined with erythrostasis, which is greatest in the bone marrow, has produced corpuscular hemolysis.[21] The erythrocyte then becomes as rigid and fixed in its form as a block of ice as it moves and abuts against fixed objects. The fact that salmonellosis has produced osseous changes in patients with sicklemia is explained by the knowledge that hyperthermia, leukocytosis and infection all produce a greater competition for oxygen and, therefore, produce a consequent anoxemia.[13,11,14,53] Thrombocytosis, a decreased prothrombin level and an increased fibrinogen content of the blood at the time of, or just prior to, an episode of sicklemic vascular blockade have been observed.[39] These facts suggest that an altered coagulability of the blood is a further trigger mechanism, such that the fibrin network is altered, and the sickling process releases more free thrombin and thromboplastin. This sickling renders the erythrocyte less capable of passing through small capillaries and thus leads to mechanical obstruction. Stasis with consequent stagnant anoxia ensues. With the fragmentation of the sickle cells, an increasing concentration of coagulable factors accumulates, thus facilitating thrombosis and infarction of bone.

Histologic studies have done much to substantiate the occurrence of thrombosis and infarction within the skeleton in all the sickle cell disease variants. Symptoms of cerebral[20,63] and renal[1] origin have been correlated at autopsy with myriads of sickle erythrocytes obstructing cerebral or renal vessels in patients without anemia. Therefore, on a priori grounds, one should anticipate that infarctions of the skeleton might ensue in a similar manner. When a Negro female who died while experiencing severe back pain was autopsied, sections of the vertebrae revealed cellular components that were scattered and surrounded by abundant formless debris, marrow cells that could not be recognized because of prenecrotic change, multiple small hemorrhages between necrotic depot fat cells, iron-staining material and tangled masses of sickle erythrocytes.[31,34] The skin and muscle biopsy taken from a 21-year-old Negro with pain and tenderness in the knee, the thigh and the shoulder exhibited capillaries and venules that were crowded and distended by sickle erythrocytes and a delicate fibrin meshwork.[23] The very shape of the sickle erythrocyte predestines it to obstruction. Filiform erythrocytes in the bone marrow may be 40 micra in length; they may be enlarged at one end, giving them a club shape; or they may actually suggest masses of hemoglobin-containing tissue that may have torn away from another limb of an erythrocyte.[15] A "focal necrosis" has been described destroying soft tissue and injuring the bony trabeculae so that necrotic marrow was replaced by loose granulation tissue while bone repair was also in evidence.[17] Extensive fibrosis, plasma cells, areas of chronic *inflammatory reaction*, extensive narrowing of the medullary cavity of the femur and thickening of the cortex

were described in the hip of a young Negro male with sicklemia who exhibited cystic degeneration of one hip and died eventually in a sickle cell crisis.[3] Changes in the density of the bone in necrosis may result from atrophy of disuse, creeping replacement of dead bone by new bone, collapse of dead bone bordering joints, compression of dead trabeculae, infiltration of bone sand into marrow spaces, and calcification of the line of demarcation in the interior of old stationary necrotic areas located in the medullary and the cancellous regions.[38] Microphotographs of the capillary blockades formed by conglutinated sickle erythrocytes were displayed recently by Leong.[10]

The following changes have been noted in patients displaying either crisis or anemia:

The medullary cavity may show peculiar striations of the long bones;[13,19] coarsening of the trabecular pattern of the mandible and the maxillary process;[19] widening of the medullary cavity;[13] narrowing of the medullary cavity,[13,30] grossly irregular and rough new bone formation within the cavity[13] and complete obliteration of the cavity.[30] The cortices of the long and the short bones may be thickened, show variations in density[13,30] and periosteal elevation.[19,13] The vertebrae may show infarctive sclerosis and subsequent healing of a body.[32] "Fish-mouth" biconcave vertebrae,[13,24,32] diffuse sclerosis in the dorsolumbar spine,[38] collapse of the vertebrae[29,24] and shortening of all vertebral dimensions[13] have been described. The hips may show coxa malum senilis in a young patient,[37] aseptic necrosis of the head of the femur[14,38] and coxa plana.[34,38] When the thalassemia and the sicklemia genes are combined, the head of the femur may be severely mushroomed and simulate Legg-Calvé-Perthes disease in the child.[46] Radiolucent destructive lesions are reported in the wrist,[35] in both first metatarsals, in multiple osseous separate sites and in a distal femur and a tarsal navicular.[32] Herrick's original report of the first case to be documented in the literature exhibited a monarticular knee joint effusion,[27] and the syndrome of severe polyarthritis associated with a normal sedimentation rate has been well substantiated.[5] It has been estimated that it takes 3 weeks after the onset of pain and effusion for osseous lesions to become visible radiologically.[37] Other miscellaneous lesions associated with either crisis or anemia include delay in the closure of the epiphysis,[13,51] anterior bowing of the tibia,[24] bilateral sclerosis of the mesial surface of the sacro-iliac joints and aseptic necrosis of the humeral heads.[14,20,38]

Since 1942 much evidence has accumulated to prove that the occurrence of sicklemia in conjuction with osseous changes is not mere coincidence. A 24-year-old nonanemic colored male complained of a painful hip. His roentgenograms revealed a cystic degeneration of the femoral head, his smear showed sicklemia, and he died later in sickle cell crisis.[3] Another young Negro male adult presented an irregular, unilateral, flattening and eburnation of the femoral head at the same time that muscle biopsies of the thigh showed proven sickle cell thrombosis and infarction.[12] Cases are also reported of middle-aged Negro males and females whose only manifestation of sickle cell disease was that their smear revealed 100 per cent sickling and their roentgenograms showed bilateral aseptic necrosis.[38] Conly and Smith collected 18 patients who represented various genetic variants of sickle cell disease and whose hips all revealed changes suggestive of Legg-Calvé-Perthes disease Nine of these cases were either "S-C disease" (sicklemia) or unclassifiable. Only one of them exhibited bilateral avascular necrosis.[58] Similar types of hip disease have been reported in combinations of thalassemia and sickle cell hemoglobin.[46] One sicklemic patient has been reported with increased sclerosis of the ossification centers of the humerus, and another with bilateral sclerosis of the iliac crest.[20] However, Conley and Smith feel that these scattered areas

of sclerosis are probably very rare in the genetic variants of sickle cell anemia.[8]

The thrombotic-infarctive rationale for the osteochondritis-dissecans-like lesions described in this case receives further support from the original works of Koch and Axhausen,[16,29,33] who postulate that an "obstruction of the entire capillary area of nutrition" by emboli was at fault. Although some workers have disputed this, claiming that there are no true end anatomic arterioles in these areas, it does not mean that the vessels could not still be functionally end arterioles.[60] Fairbank hesitated to follow those who claimed that trauma could explain these lesions;[16,33,44] he felt that some other basic pathologic state must accompany the traumatic factor.[16] Perhaps it is the sickling diathesis, at least in those patients who possess Negroid germplasm, that supplies the nontraumatic factor to which Fairbank alluded. The incidence of the trait varies from 7 per cent[11] to 14 per cent,[22] and, since the ratio of sicklemic patients to sickle cell anemia patients varies from 7 to 1[60] to 40 to 1,[11] it is probable that changes mentioned in this report might be noted with greater frequency. These changes might also be suspected in apparent Caucasians, as there are now 26 authenticated cases of sickle cell disease in Caucasians in whose immediate hereditary background there were no Negroes. However, most of these cases exhibited some evidence of North Mediterranean, Mexican, Mayan or Indian ancestry, and some of them are examples of disease due to a combination of genetic variants of sickle cell disease combined wth thalassemia either major or minor.[37,41,71]

The statement that "the ability to sickle appears to be attended by no pathologic consequences in the majority of individuals" is probably a fairly accurate estimate of the situation,[40] since most of the small focal lesions heal by creeping substitution and are relatively asymptomatic. However, in spite of the fact that sicklemic skeleton changes may be uncommon, there is no foundation for dismissing the trait as unimportant,[13,2,32,60,61,70] for stating that "the bones of the Negro with the sickle cell trait, in the absence of hemolytic anemia, are negative on roentgen examination," or for claiming that "no residual deformity or demonstrable roentgen changes are present after attacks of severe migratory joint pains."[13]

SUMMARY

A case report of a 24-year-old Negro male with the proven sickle cell trait and with multiple osseous lesions in the shoulder, hips, sacro-iliac joints, knees, tibias, fibulas and subtalar joints has been presented and the significance of this condition discussed.

CONCLUSIONS

Sicklemia is not a benign trait and can be associated with multiple musculoskeletal derangements that may increase significantly the morbidity of the patient. There is no parallelism among the degree of anemia, the severity of the sickle cell disease symptoms, the rate of destruction of the erythrocytes, the extent and the severity of the roentgen demonstration of osseous changes, and the musculoskeletal symptoms. Clinicians should abandon the misnomer *sickle cell anemia* and *sickle cell trait* and employ the designation *sickle cell disease*. The anemia, though the most popular sign, is not the essential defect, and not even a consistently dangerous one. The mortality and the musculoskeletal morbidity of the disease are not related to the anemia but to the sites of vascular obstruction. The symptoms and signs in a patient with sickle cell disease may be completely referable to the musculoskeletal system without affecting any other system.

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30

The Sesamoids of the Great Toe—The Pedal Polemic

Report of 3 Cases

MORTON H. LEONARD, M.D.*

Review of the world literature on the sesamoids of the great toe reveals a surprising difference of opinion regarding their development and pathology. This literature began to accumulate during the Middle Ages. Inge and Ferguson[5] cite Garrison,[4] who relates that the medial sesamoid was known as the bone "luz." Rabbi Uschaia thought the bone luz would be the nucleus for reconstitution of the body at the millenium. Inge and Ferguson believed that a fracture should not be diagnosed unless callus formation was seen. They found divided sesamoids in 10.7 per cent of roentgenograms of 1,027 patients over the age of 10. In their opinion, a painful sesamoid could be due to arthritis, bursitis or displacement. They did not feel that there was an entity of sesamoiditis but that this condition was actually a traumatic arthrosis. Excision of the painful sesamoid in 41 feet gave good results.

Piergrossi[10] pointed out that the x-ray diagnosis of a fracture of the sesamoid was exceedingly difficult because of overlying shadows. He and Key and Conwell[6] recommend excision of a painful sesamoid if symptoms last over 2 months. Bizarro[1] indicated the difficulty of ascertaining the mechanism of fracture. He felt that frequently the fibular sesamoid escaped injury because it moved fibularward.† T. G. Orr[9] reported 24 cases of fracture of the sesamoid up to 1918. Freiberg[3] related finding only 1 bipartite sesamoid in over 1,000 roentgenograms. He said that if there was a history of trauma and comminution was present, there was no argument about the possibility of fracture. He added that it was an academic question as to whether or not there was fracture if there were symptoms from the sesamoid. The technic of Müller[8] for taking an axial view of the sesamoid is outlined in the English literature by Burman and Lapidus.[2] These authors found 78 bipartite sesamoids in 100 roentgenograms.

Those who are interested in a complete summary of the literature with a radiographic, clinical and pathologic study of the sesamoids of the great toe should refer to the work of Kewenter.[6] He studied a series of 424 females and 370 males from 14 to 65 years of age without signs and symptoms in the region of the sesamoids. He found partition of the sesamoids in 33.5 per cent. The percentage in females was 36.6 and in males 30.1. The tibial sesamoid was bipartite much more often than the fibular. Par-

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† It is suggested that to avoid confusion the medial sesamoid be called the "tibial" and the lateral sesamoid the "fibular."

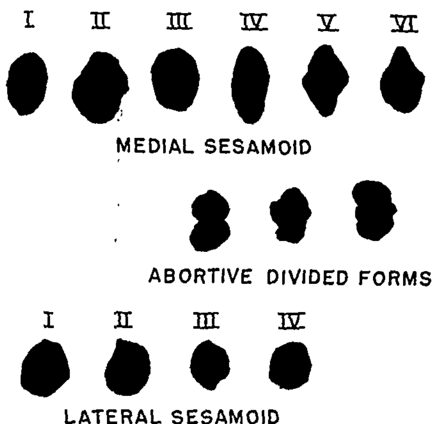


FIG. 1. The Roman numerals indicate the order and the frequency of sizes and shapes of the great toe sesamoids. (Kewenter, Y.: Acta orthop. scandinav. [Supp. 2], p. 42, 1936) The use of "tibial" to indicate medial and "fibular" to indicate lateral is preferred.

tition can rarely result in as many as 4 pieces to a sesamoid. The size and the shape of these bones in their order of frequency are illustrated in Figure 1 and the types of partition and their frequency are shown in Figure 2. Kewenter analyzed the literature critically and stated that up to 1936 60 cases of fracture of great toe sesamoids had been reported. Ten of these were in combination with other fractures. He concluded that isolated fracture of these sesamoids was rare. The diagnosis is to be made with caution. The criteria for the diagnosis are callus formation, histologic

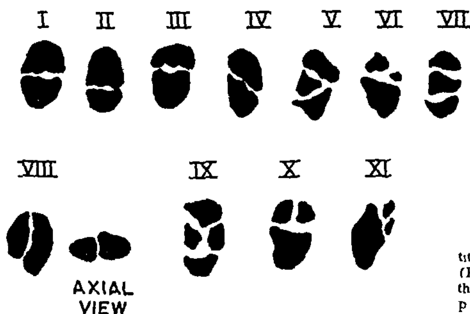


FIG. 2. The types of partition and their frequency. (Kewenter, Y.: Acta orthop. scandinav. [Supp. 2], p 48, 1936)

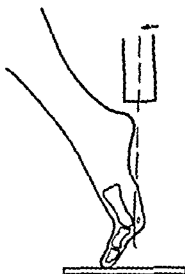


FIG. 3. Technic of taking axial view. (Müller, W.: Beitr. klin. Chir. 134:315)



FIG. 4. Longitudinal division of a fibular sesamoid in a 17-year-old female.

evidence of fracture or a radiograph showing division not present prior to injury but there after it.

Kewenter pointed out that more than one center of ossification was more common in the tibial sesamoid. Usually, ossification is completed in from 1 to 2 years. The time of appearance of ossification was studied in 239 females and 226 males aged from 5 to 16 years. In addition, 24 females and 31 males aged from 2½ to 10 months were studied. The first appearance of ossification in a female was noted at the age of 7 years and 2 months; the latest, 10 years and 9 months. The average age of appearance in females was 9.1 years. In males, the earliest appearance was about 10 years; the latest, 12½; average, 11.1 years.

Kewenter sectioned 520 sesamoids in 130 cadavers varying in age from 1 to 100 years. He found undivided sesamoids of homogeneous structure, divided sesamoids, fractures of solid sesamoids and fractures of partite sesamoids. It was noted that partite sesamoids fractured more often and from lesser trauma. Arthrosis deformans was noted in 10 per cent of these cadavers.

Kewenter concluded from his clinical, radiographic and pathologic investigations that pathologic change did occur in the sesamoids of the great toe. These changes are rare and can be asymptomatic He pointed out that there was no typical sesamoid disease and that the sesamoids were not unusual bones but were subject to fracture and arthrosis deformans.

Painful sesamoids do occur and should be studied by careful clinical examination, laboratory examination, including blood uric acid determinations, and roentgenographic studies. A useful clinical test for pathology in the sesamoid is to palpate the bone with the great toe in varying positions. Pain and tenderness shift with the sesamoid. In roentgenographic diagnosis the axial view is most important (Fig. 3).

Case 1. A 17-year-old female complained of pain in the region of the right great toe for 2 months She denied injury. On examination there was tenderness isolated to the fibular sesamoid. This tenderness shifted as the sesamoid was moved. Radiographs made at the time of the first visit, on January 21, 1957, showed a definite line of division in the fibular sesamoid (Fig. 4) She was treated with arch supports. On March 29, 1957, she was asymptomatic Roentgenograms made on December



FIG. 5 (*Left*) Anteroposterior view showing division of fibular sesamoid. (*Right*) Axial view. The absence of overlying bone shadows permits better demonstration of the longitudinal division.

19, 1957, show what is either a nonunion of a fracture of a fibular sesamoid or, more likely, a bipartite sesamoid (Figs. 4 & 5).

It is my opinion that the pathology was injury to a bipartite fibular sesamoid

Case 2. A 38-year-old male sought advice on August 15, 1952, with the complaint of pain on weight-bearing in the region of the left great toe. Examination was negative except for shifting tenderness associated with the tibial sesamoid. Radiographs made at the time of the first visit showed irregularity of outline and marked alteration of the trabecular pattern of the tibial sesamoid, which was excised on August 18, 1952 (Fig. 6). At surgery it was noted that the cortex was intact. A roentgenogram was made of the specimen (Fig. 7). The pathologic report was as follows:

"An oval-shaped piece of bone that measures 2 cm in greatest diameter On sectioning one sees a firm, grayish-white cortex that measures 2 mm. in greatest diameter. Beneath the cortex there are grayish-white cancellous bone and an extremely firm translucent nodule measuring 5 mm. in greatest diameter. The section shows a piece of bone. The bone marrow is replaced by mesenchymal tissue, which is intimately *associated with the bone. In those places where* the mesenchymal tissue is closest to the bone, a number of giant cells and some atrophy of the bone were noted. In other places there are deposits of golden-brown pigment. Also present are numerous small irregular cytic spaces."

It is believed that this is a case of a bipartite tibial sesamoid as demonstrated by radiographs of the specimen. The other changes are secondary to trauma.

Case 3. A 30-year-old male came under my care on November 3, 1952, complaining of pain in the right great toe on weight-bearing during the previous 6 months. Radiographs made elsewhere on October 20, 1952, showed no evidence of bony abnormality (Fig. 8, *top, left*). An axial view was not available. There was shifting tenderness over the tibial sesamoid. The axial view showed a bipartite sesamoid (Fig 8, *top, right*). Treatment was with meta-



FIG. 6. (*Top, left*) Anteroposterior view of the great toe joint. Changes are present in the tibial sesamoid but difficult to see because of overlying bone shadow. (*Bottom*) Lateral view of the left great toe and its sesamoids. Note the irregular outline of the tibial sesamoid. It is difficult to know which sesamoid is involved from this view alone even in conjunction with the anteroposterior view. (*Top, right*) Axial view clearly shows the roentgenologic changes in the tibial sesamoid since there are no overlying bone shadows.



FIG. 7. (*Left*) Anteroposterior roentgenogram of specimen. The arrow indicates a division of the sesamoid. (*Right*) Lateral view of specimen. The arrow notes the abnormal caudal projection of the sesamoid.



FIG 8. (*Above, left*) Anteroposterior roentgenogram of a painful tibial sesamoid. (*Above, right*) Axial view made at the time of the first visit (*Bottom*) Axial view made on May 12, 1953.

tarsal bars. By May 12, 1953, the patient's symptoms had somewhat subsided. Axial radiographs made on that date showed no change (Fig. 8, *bottom*).

During the course of treatment this man's condition was diagnosed as a fatigue fracture of the tibial sesamoid. It is evident that this represents a case of a vulnerable bipartite sesamoid that had been injured. The axial view demonstrated the divided nature of this tibial sesamoid.

SUMMARY AND CONCLUSIONS

Much has been written about 2 small bones—the sesamoids of the great toe. These bones are osseous and can suffer the pathologic changes of bone. Isolated fracture of the sesamoids is rare. The use of the terms *tibial* and *fibular* to describe the medial and the lateral sesamoids will minimize confusion. The test of shifting pain and tenderness is useful in the diagnosis of pathology of the sesamoid bones. In the study of causes of pain in the region of the great toe, gout as a diagnosis should be considered. The axial roentgenogram should be included in the radiographic study of the sesamoids of the great toe.

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Nonunion of First Thoracic Spinous Process

Case Report

Duncan C. McKeever, M.D.

The patient, a 37-year-old white male, presented himself on May 10, 1956, with the following history:

In 1951, he was driving a bus across an open field when the left front wheel dropped into a hole, stopping the bus instantly. The steering wheel was jerked violently, and he was thrown almost completely through the front window. He felt something pop in his upper back and at the time could hardly breathe. The back was taped for 2 weeks. Roentgenograms were said to be negative.

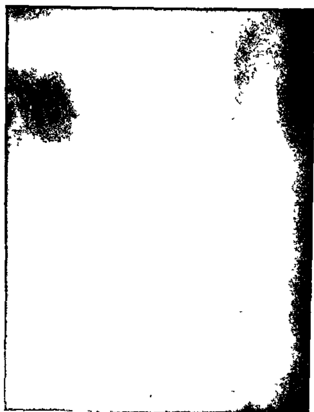


Fig. 1 See text.

For the next 5 years the patient continued to have daily headaches, almost constant in character, located in the back of the head and over the sides of the head toward the eyes. They were definitely aggravated by fatigue. He also had pain radiating into his chest and down both arms. There was limitation of motion in the neck when the pain became severe. The condition had made him extremely nervous. Numerous examinations had failed to reveal any cause for the condition.

Examination revealed a fairly well-nourished and well-muscled male, carrying himself in somewhat faulty posture with forward projection of the head. The scalenus muscles were in some spasm, as were all the neck muscles. There was tenderness over the scalenus muscles. The only positive finding was of acute tenderness over the spinous process of the 1st thoracic vertebra.

Multiple oblique roentgenograms were taken to try to throw the lower cervical and upper thoracic spinous processes into profile. One of these was successful and revealed a fracture of the spinous process of the 1st thoracic vertebra about 1 inch from its tip with gross displacement and an obvious nonunion (Fig 1). After examination of this roentgenogram, re-examination of the anteroposterior view (Fig. 2) revealed a duplication of the spinous process of the 1st thoracic vertebra: one of the images is the fractured-off piece; the other is the remaining base of the spinous process.

Twenty-four hours of head traction produced complete symptomatic relief.

The fractured-off spinous process was removed surgically. At the time of operation the contacting surfaces at the fracture site were very badly eburnated as a result of prolonged friction.

The operation afforded immediate complete relief of all symptoms. The patient was dismissed from the hospital 4 days postoperatively. He was placed on postural exercises. He returned to work as soon as his stitches were removed.

Since discovery of this case, the author has had occasion to see 3 other cases in which fracture of a thoracic spinous process was followed by union in a position that caused painful impingement. Two of these were relieved by excision of the involved process. The other case did not present sufficient symptoms to warrant operation. It is the author's opinion that frequently this condition is overlooked.

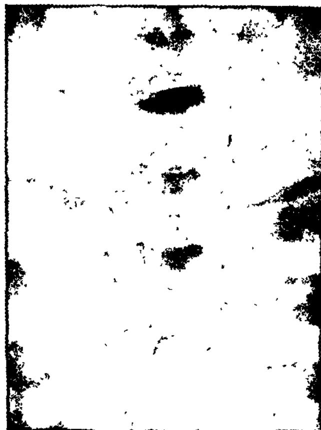


Fig. 2. See text.

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The Cushion-Socket Below-Knee Prosthesis

ERNEST M. BURGESS, M.D.,* AND EUGENE COLEMAN, C.P.

During the past decade, major improvements in limb design have transformed the field of prosthetics far beyond the highest expectation of most of us. The generally satisfactory function experienced by below-knee amputees has tended to focus a greater degree of attention on the more pressing problems of limb substitution at other levels throughout the upper and the lower extremities. However, critical evaluation of conventional below-knee prostheses now available would indicate that the below-knee level of amputation, no less than any other, calls for concerted study to resolve the many problems inherent here. Experience with the closed cushion socket, or Coleman limb, leads us to believe that this prosthesis presents definite advantages for certain

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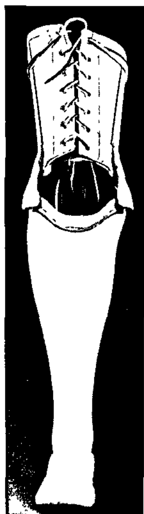


FIGURE 1



FIGURE 2

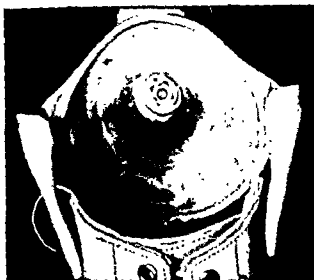


Figure 3



Figure 4



Figure 5

below-knee amputees. This report outlines briefly the field of usefulness and the principles of design of the Coleman limb.

In our experience, no below-knee amputee ever is completely happy with the fit and the comfort of his limb. Of course, the basic problem has *to do with the necessity* for weight-bearing below and about the knee, which area is neither by function nor by anatomy designed for such purpose. A wide variety of limb variations and modifications have been used to ease the burden of socket weight-bearing. Meticulous socket fit is the first requisite. In most cases, one or more interposed socks of suitable material will cushion the stump sufficiently to increase comfort. This comfort can be enhanced in certain circumstances by the use of a soft socket. Certain amputees find the soft-socket limb almost indispensable. A few below-knee amputees will experience greatest comfort and efficiency with a suction socket. In general, however, our experience *with the* suction socket *for* the below-knee amputee has been disappointing; socket tolerance has been poor.

A wider, local distribution of weight-bearing is useful and can be accomplished by *modifying the below-knee socket to contour* to the lower border and sides of the patella; also, a well-molded thigh cuff will absorb a surprising degree of the total weight transmitted through the extremity. Studies would indicate that, actually, a high-thigh cuff may

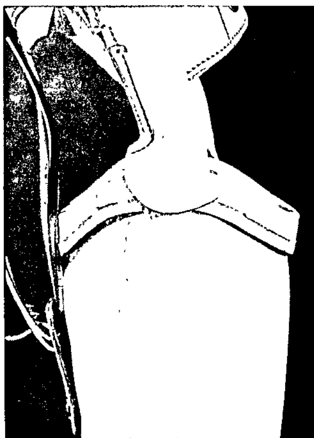


FIGURE 6

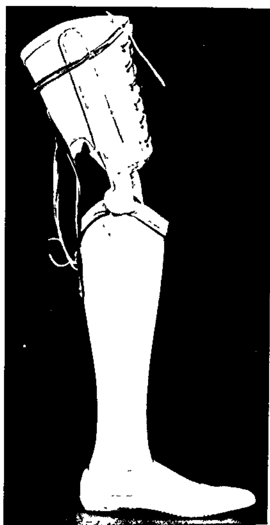


FIGURE 7

assume as much as 50 per cent of the total weight load. In difficult circumstances, and with extremely poor stump-socket tolerance, a major portion of the weight can be transmitted to the pelvis through rigid side uprights to an ischial ring or through a semi-rigid thigh component with a posterior wood, metal or plastic support contoured to the upper end of the thigh and the ischium. Another mechanical device that sometimes is of value in reducing stump-socket weight load is an end-bearing sling in the socket capable of taking a minor degree of pressure directly on the end of the stump.

Proper limb alignment is fully as essential as proper socket fit. Functional alignment includes correct placement of the knee-joint hinges and a properly placed and balanced ankle-foot assembly. Most below-knee amputees prefer a single-pivot, two-way ankle mechanism with the flexible toe break. Ankle dorsiflexion is limited to simulate "push off" and plantar flexion restricted sufficiently to permit ease of toe clearance. Incorporation of lateral or universal movement in the ankle-foot device, such as cable or Navy ankle, the SACH ankle-foot, or one of the other several commercially available lateral ankle-foot assemblies, may add to the comfort of the stump-socket fit and absorb some of the repeated shock of weight-bearing. Certain amputees experience increased comfort and limb tolerance with ankle-foot mechanism of this type. A number of other limb variations of value are in current use, including flexible knee hinges with suprapatellar suspension and the slip-socket and the split-socket limbs. All on occasion will aid the prosthetist in

meeting the basic problems of stump-socket tolerance.

The fact remains that, despite the variety of technics designed to reduce weight load, friction and stress on the proximal tibia and about the knee, the amputee still must take the major portion of his weight at this site with each step. The skin and the soft tissues about the upper tibia and the knee joint accept this alien task reluctantly. At some time or other, every below-knee amputee will experience the characteristic problems of undue pressure, minor or major irritative skin lesions, tender stumps and local or diffuse sharp pain.

The cushion-socket prosthesis here presented was developed for certain difficult, short below-knee amputees who had tried one or all of the available prostheses and still presented the problem of poor limb tolerance. This limb is designed to compensate for torsional and pressure stress at socket level by means of rubber cushioning between the socket and the shin-ankle-foot assembly. The present design is illustrated in Figures 1 to 8. The limb is constructed of wood or laminated plastic. The socket is closed and is contoured in the usual manner. It may be carried up to permit patellar weight-bearing if the surgeon and the prosthetist so desire. A molded thigh lacer and properly placed knee hinges are fitted as with the conventional prosthesis. The socket is cushioned into the shin of the limb by a rubber ring and a coating of rubber extending down a short distance from the ring along the outer surface of the socket. The design permits a small degree of universal motion between the socket and the shin-ankle assembly without sacrificing stability. We have had no trouble with instability of the stump within the socket; nor has the socket tended to withdraw or pull away from the leg.

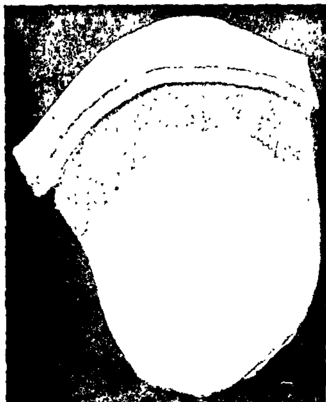


Figure 8

Our initial experience with this limb in certain difficult cases indicated its worth. We have extended its use now to 22 amputees. As our experience in both design and types of user-amputees has broadened, it is evident to us that the principle of the cushion socket is valid. We would recommend an increasing clinical evaluation of this limb and of the cushion-socket principle for the below-knee amputee.

CONCLUSIONS

The authors have presented their experience with a below-knee prosthesis incorporating the principle of the closed cushion socket. The basic problems inherent in below-knee limb fit have been outlined briefly. Our evaluation of the cushion-socket prosthesis would indicate that it fills a definite need in the proper management of certain below-knee amputees.

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